Part 2:

Research and Ecology

WILD RICE PLANT DEVELOPMENT AND SEED PHYSIOLOGY

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ABSTRACT

Environmental influences on the development of wild rice (*Zizania* sp) have been investigated at the University of Minnesota since 1972. Although much research was done on plant development before 1972, we have been able to significantly add to our knowledge about the physiology and development of wild rice. Flowering time of *Z. palustris* and *Z. aquatica* is very responsive to day length and temperature. Both species flowered earlier when subjected to short days compared to longer days. Plant size and floret number were reduced when grown with short days compared to longer days. *Z. texana* did not respond as much to day length. The differences in flowering time due to day length were negated by growing the plants at higher temperatures. All flowers in the embryonic state have both male and female initials, but in most plants only the male parts develop in the lower part of the panicle and the female (grain) develops in the upper part. In some plants all flowers only develop female (grain) parts. The wild rice plant has a relatively high requirement for plant nutrients to produce a pound of dry matter. Most growth and dry matter production occurs during the reproductive phase. Pale leaf color during growth is a good indicator of nitrogen deficiency. Seed dormancy may be caused by the impermeable pericarp and by an imbalance of chemical growth promoters and inhibitors. Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo. Seeds can be maintained for viability if dried to a certain moisture level and then stored at temperatures below freezing.

CLASSIFICATION OF WILD RICE

C. Linnaeus in 1753, using a plant specimen sent to J. F. Gronovius in Leyden, Holland, by John Clayton, which he collected in Virginia in 1739, first classified wild rice. Based on the description of Gronovius, Linnaeus designated wild rice as *Zizania aquatica* for Clayton's herbarium sample. *Zizania* is a small genus of aquatic grasses in the tribe *Zizanieae*, which immediately follows the tribe *Oryzeae*, to which rice *Oryza sativa* belongs.

Originally, there was some confusion about the number of species of *Zizania*, but the consensus today is that there are four species of *Zizania*. Linnaeus (1753), Dore (1969), Dore and McNeill (1980), and Duvall and others (1993) recognized two species that are broken out of *Z. aquatica* and *Z. palustris*. The subspecies of *Z. aquatica* are varieties *aquatica* and *brevis*, and for *Z. palustris*, they are varieties *palustris* and *interior* (Warwick and Aiken 1986). Dore and McNeill (1980) and Aiken and others (1988) defined the species' differences based on differences in the lemma and palea of the pistillate spikelets and number of spikelets per branch. *Z. palustris* is the large-seeded type that grows throughout the Upper Midwest and southern Canada and is cultivated in Minnesota, Wisconsin, Canada, and California. *Z. aquatica* grows from the St Lawrence Seaway down the Eastern Seaboard to Florida and Louisiana. In the early literature, *Zizania aquatica* was used as the binomial for all of the annual species of wild rice. In addition to *Z. aquatica* and *Z. palustris*, there are two other species, *Z. texana*, a perennial-type localized in the San Marcos River in Texas, and *Z. latifolia*, an Asian species. The distribution of the three North American species is shown in Figure 1. The categories recognized by Dore (1969) are summarized in Table 1.

Z. aquatica var. *aquatica*, southern wild rice, is an

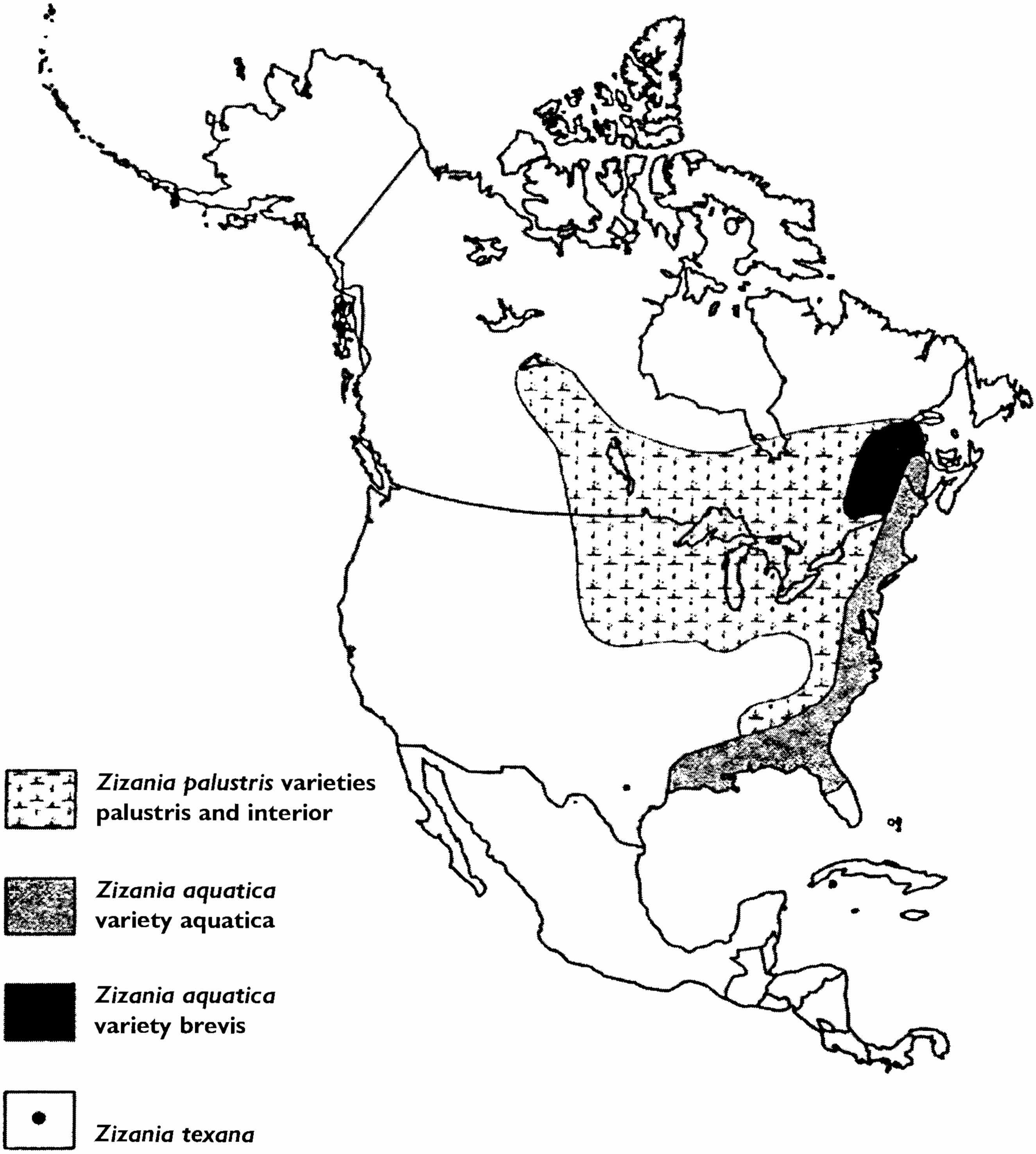

Figure 1. Distribution of wild rice in North America.

annual found on the muddy shores of streams in southern Ontario and Quebec, southward to Florida and Louisiana. (See Figure 2.) It is a tall, 180- to 240-cm plant with wide (2.5- to 5-cm) leaves. The panicle is large (50 cm long), with many thin, needle-like kernels that shatter before fully mature. *Z. aquatica* var. *brevis*, estuarine wild rice, is an annual and is found on the tidal flats of the St Lawrence River estuary and is a plant that is 30 to 90 cm tall with narrow leaves (1.5 cm or less wide) and panicles 10 to 25 cm long. The number of seeds on the panicle are few but plumper than those of *Z. aquatica* var. *aquatica*.

Table 1. Classification of wild rice species.

Classes Used by Dore	
Annuals Found in the United States and Canada	
1a.	*Z. aquatica* var. *aquatica* L. Southern Wild Rice
1b.	*Z. aquatica* var. *brevis* Fassett Estuarine Wild Rice
2a.	*Z. palustris* var. *palustris* L. Northern Wild Rice
2b.	*Z. palustris* var. *interior* (Fassett) Dore Interior Wild Rice
Perennials Found in the United States and Asia	
3.	*Z. texana* A. S. Hitchc. Texas Wild Rice
4.	*Z. latifolia* Turcz. Manchurian Water-Rice

Z. palustris var. *palustris*, northern wild rice, is an annual and is found widespread in southern Canada from New Brunswick to Manitoba and adjoining Ontario and abundant in the North Central States. The plant ranges from 90 to 240 cm tall with narrow leaves and panicles with numerous male and female flowers. (See Figure 3.) It can be found in water up to 120 cm deep and is the variety most frequently harvested for its large, edible seed.

Z. palustris var. *interior*, interior wild rice, is found on muddy shores and in water up to 30 cm deep along rivers in southeastern Manitoba and adjoining Ontario and abundant in the North Central States. It is generally slightly taller and with wider leaves than *Z. palustris* var. *palustris* but with more seeds on the panicle. This variety of *Z. palustris* is also widely harvested for its large seed.

Z. texana, Texas wild rice, is a perennial and can only be found in localized areas in the San Marcos River in Texas. The plant has many decumbent stems that can be more than 300 cm long. (See Figure 4.) The panicles are 18 to 20 cm long and are similar to those of *Z. palustris* var. *palustris*. The small seeds are only about 4 mm long. This specie is on the U. S. Endangered Species List.

Z. latifolia, Manchurian water-rice, is a perennial and is a native grass of Manchuria, Korea, Japan, Burma, and northeast India. It has coarse subterranean runners, and the base of the plant often becomes infected with a fungus. It is cultivated in Japan, China, Taiwan, Vietnam, Loas, and Cambodia, and the plants are systemically infected with the fungus. (See Figure 5.) The bottom of the stems infected with the fungus (see Figure 6) is then harvested as an edible food (vegetable), called *Makomo-take* in Japan.

The North American *Zizania* species are all $2n = 2x = 30$ (Bolkhovskidh et al. 1969). Fifteen bivalents (eight rods and seven rings) are present at meiosis. *Z. latifolia*, the Asian species, is $2n = 2x = 34$. In interspecific crossing experiments, Duvall and Biesboer (1988) noted a crossing incompatibility in that *Z. aquatica* was required as the female parent in crosses with *Z. palustris* in order to obtain seed set.

Z. PALUSTRIS VAR. *PALUSTRIS* PLANT DEVELOPMENT

Z. palustris is an annual, cross-pollinated species that grows in flooded soils. In Minnesota, it matures in about 120 days and requires about 2600 growing degree days (4.4°C base) (Oelke et al. 1982). The

Figure 2 (left). A plant of *Zizania aquatica* growing in Louisiana. The plant is about 213 cm tall with large open panicles.

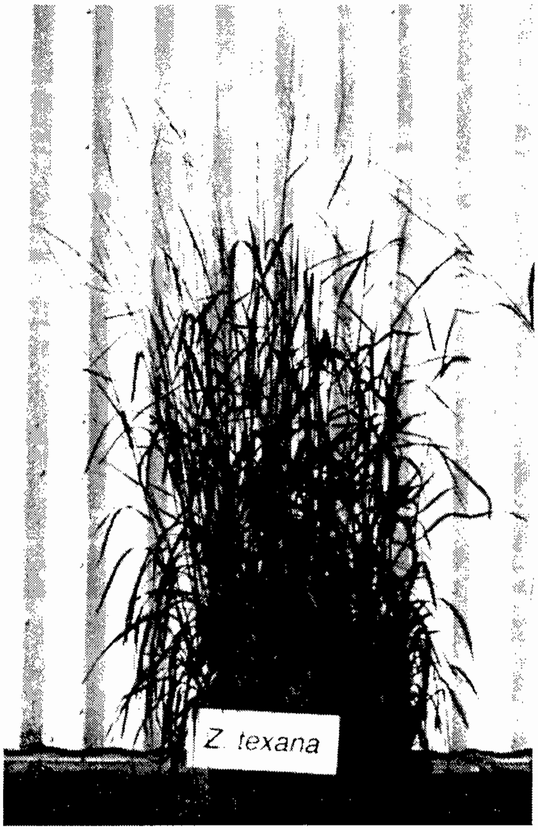

Figure 4 (above). Three plants of *Zizania texana* that were grown in a growth chamber and are about 54 cm tall. The plants grow upright when not grown in flowing river water. The plants have the ability to develop long stems in flowing water.

Figure 3 (left). A plant of *Zizania palustris* growing in Minnesota and in shallow (15-cm) water allowing production of many tillers. The plant is about 54 cm tall and was selected from lake types in Minnesota for commercial production.

Figure 5. *Zizania latifolia* being grown in Japan for production of the edible fungal infected base of the stem called *Makomo-take.*

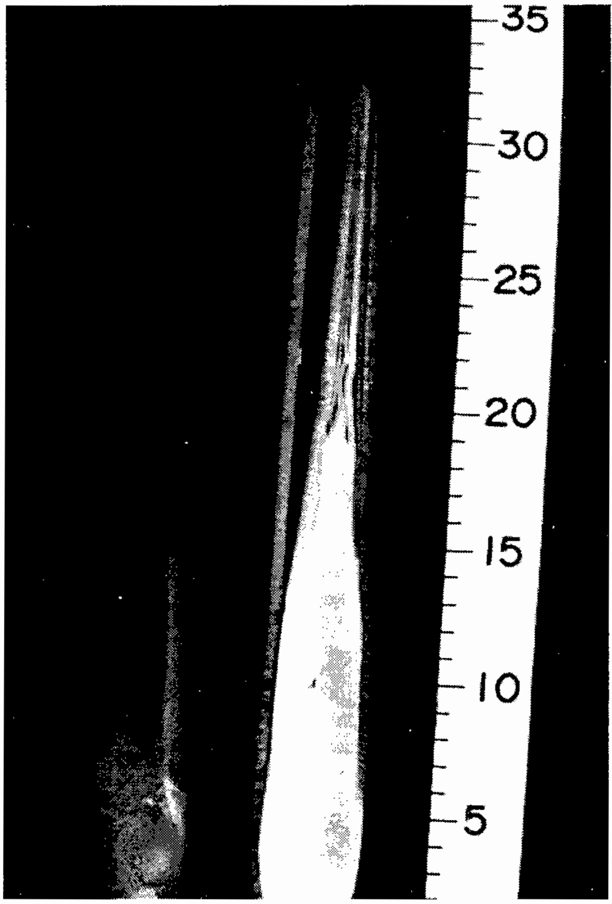

Figure 6. The stem base of *Zizania latifolia* that becomes enlarged when infected with a fungus (*Ustilago esculenta*). This infected base is harvested as an edible food (vegetable) in Asia.

Figure 7. The seed on the left has the coleoptile emerged, indicating germination. Soon after, the primary root (curled) and first true leaf emerges, as seen in the right seedling.

growth cycle begins when germination occurs, usually when soil/water temperatures reach 5.6°C. Germination is evident when the coleoptile breaks through the pericarp. (See Figure 7.) Next, the primary root extrudes through the pericarp 7 to 10 days after emergence of the coleoptile. The seedlings have three submerged leaves after three weeks. The next two to three leaves float on the water surface, called the *floating leaf stage*. Additional leaves are aerial, varying in width from 1 to 3 cm and up to 75 cm long. Ligules are present at the leaf blade and sheath junction. Mature plants are 60 to 90 cm tall and can produce up to 50 tillers per plant. In cultivated fields, plants usually have three to six tillers. In lakes, most plants have only one or no tillers on the main stem. Stems are hollow except at the nodes, where leaves, tillers, roots, and flowers appear. Internodes are separated by thin parchment-like partitions as illustrated in Figure 8. The shallow root system has a spread of 15 to 30 cm. Mature roots are straight and spongy, have very few root hairs, and are often rusty orange in color due to oxidized iron on their surfaces. Mature plants have five or six leaves above the water per stem or tiller.

Flowers are in a branching panicle with female (pistillate) flowers at the top oppressed to the rachis, and male (staminate) flowers on branches usually spring to a near-horizontal position on the lower portion. (See Figure 8.) Variations of this panicle form include the "bottlebrush" characteristic (often associated with male sterility), in which male branches also remain oppressed, giving the panicle the compact appearance of a bottle brush. Another type is the "crowsfoot" panicle, in which the pistillate branches spread in the same manner as in *Z. aquatica* panicles. The "pistillate" trait has panicles in which male florets are replaced with female florets, resulting in a gynoecious, or all-female, panicle. We have found that the average number of female florets was 137 for a normal panicle and 382 for a pistillate panicle. Figure 9 shows the various panicle types of *Z. palustris*.

The growing point development of wild rice is similar to other grains such as oats but is closer to that of rice (*Oryza*). The vegetative growing point (apical meristem) has an apical dome that gets surrounded by leaf primordia. (See Figure 10.) The apical meristem continues to increase in size and produce more leaves. When the meristem changes to the reproductive phase, the primary branch primorida, which will develop into the panicle, gets covered with bract hairs. (See Figure 11.) The covering of the embryonic inflorescence with bract hairs is typical for aquatic species. The floral primordia eventually differentiate into lemma, palea, stamen, and pistil. It appears that all of the floral primordia have both male and female embryonic parts (see Figure 12), but only the female flowers (pistil) develop in the upper portion of the panicle, and only the male flowers (stamen) develop in the lower portion of the panicle. However, in the transition zone between the male and female portion of the panicle, sometimes the floret has a fully developed pistil and six stamens (Liu et al. 1998).

Cross-pollination usually occurs because female flowers emerge first, become receptive, and are pollinated before male flowers on the same panicle shed pollen. Sometimes the transition florets, which are located between the pistillate and staminate florets on the panicle, have both stigmas and anthers (pollen), and can therefore be self-pollinated. When viable pollen grains land on the stigma, they germinate within one hour and reach the embryo sac within two hours. Two weeks after fertilization, the seeds are visible, and after four to five weeks, they are ready for harvest. The seed is a caryopsis that is similar to the grain of cereals. The caryopsis has an impermeable pericarp, a large endosperm, and a small embryo. Grains with the palea and lemma (hulls) removed range from 8 to 16 mm in length and from 1.5 to 4.5 mm in diameter. Immature seeds have a green aleurone layer, which turns purple-black as seeds reach physiological maturity. Seeds on a given tiller mature at different times, and they mature later on secondary tillers than on main tillers.

The flowering time of *Z. palustris* plants is very responsive to day length and temperature. When the values for the Johnson and Canadian cultivars were averaged, they flowered 20 days earlier in a day

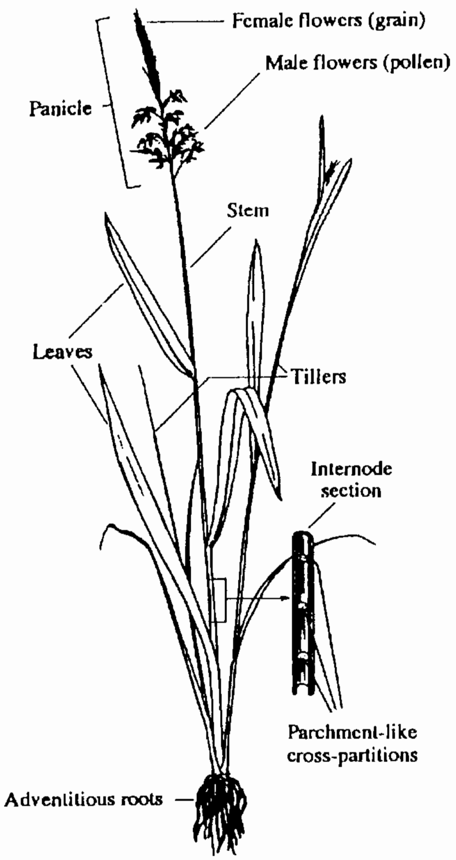

Figure 8. A drawing of a flowering plant of *Zizania palustris*.

Figure 9. Panicle types that can be found in *Zizania palustris*. The left one is an all female (pistillate), the next one a "crowsfoot," the next three "bottlebrush," the next three with branched male flowers and oppressed female flowers, and the last three on the right are shattering types that have shed their male flowers soon after pollen release.

Figure 10. The vegetative apex of a 10-day-old seedling as seen by scanning electron microscopy.

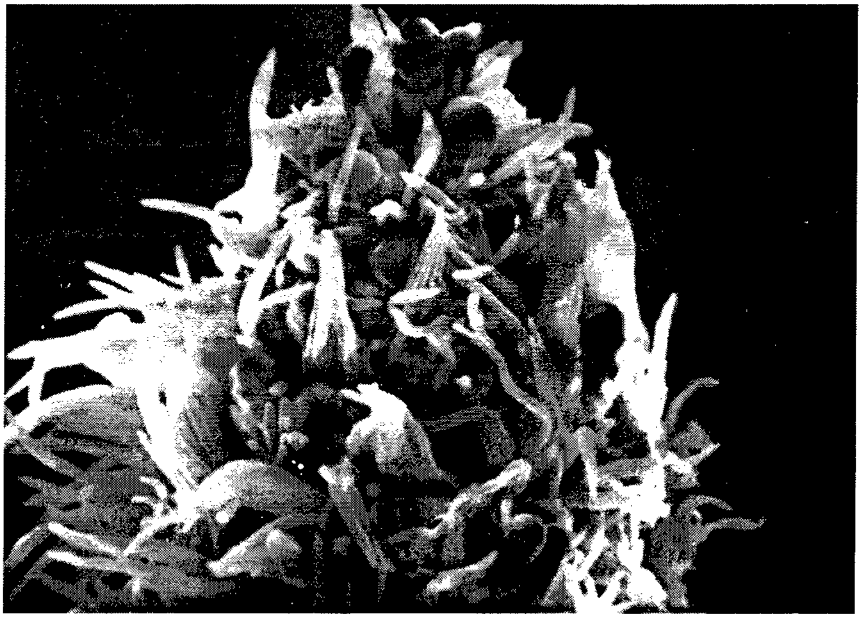

Figure 11. The floral apex, as seen by scanning electron microscopy, about 60 days after seed germination, with panicle branches elongating and the apex covered with many bract hairs.

Figure 12. An embryonic floret, as seen by scanning electron microscopy, with both female (stigma, center raised area) and male (stamens, six raised areas around stigma) primordia present. The top point is the lemma, which will eventually surround the kernel or anthers.

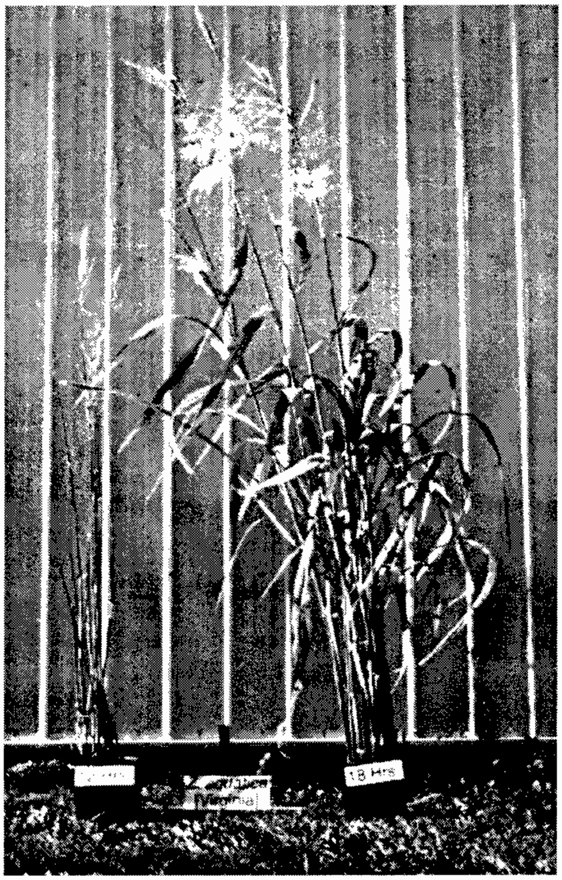

Figure 13. The plants of *Zizania aquatica* on the left were subjected to 12 hours of day length, while those on the right were subjected to 18 hours of day length. The plants on the right are about 213 cm tall.

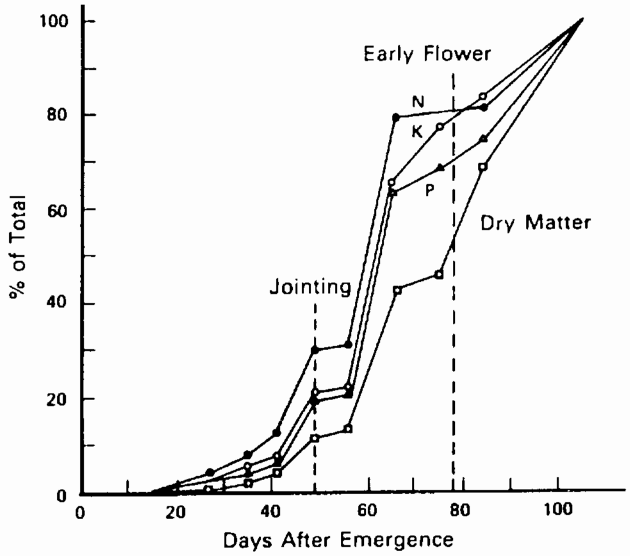

Figure 14. The accumulation of dry matter, nitrogen, phosphorus, and potassium in wild rice during the growing season.

length of 9 hours versus a simulated 15-hour (9-hour full light and 6-hour low light) day length in our studies. We also had four times fewer florets (20 vs. 80) per panicle in short- versus long-day photoperiods. These differences in flowering time and day length were negated by growing the plants in a temperature regime of 22°C versus 19°C during the day but with a 10-hour 16°C night temperature for both. Subsequent studies confirmed these results using a constant day/night temperature of 18°C and 4-hour night interruptions with low light to simulate an 18-hour photoperiod. This was compared to an 8-hour full light and 16-hour dark photoperiod. The long day again resulted in later flowering and more floret numbers per plant compared to the short day for the K2 and Canadian cultivars. A third study by Oelke and Jin (1994) compared the flowering responses of *Z. palustris*, *Z. aquatica*, and *Z. texana*. We simulated 12-, 15-, and 18-hour photoperiods by night interruption at a constant 21°C temperature and, as in previous research, *Z. palustris* and *Z. aquatica* flowered earlier when subjected to short days compared to longer days. Plant size and floret number were reduced when grown with short days compared to longer days. (See Figure 13.) *Z. texana*, however, did not respond as much to day length as did the other two species.

NUTRIENT REQUIREMENTS

Wild rice, whether growing in lakes or cultivated fields, grows in flooded anaerobic soil conditions. These conditions create a much different availability of nutrients in flooded (anaerobic) compared to upland (aerobic) soils (Oelke et al. 1982).

Flooding causes marked changes in several chemical systems in the soil that affect the nutrition of wild rice. The pH of most soils tends to change toward the neutral point (pH 7) after flooding, with acid soils increasing and alkaline soils decreasing in pH. Thus, the pH, as determined on an air-dried sample under laboratory conditions, may be different from the soil reaction at the root surfaces of the growing plant. Flooding the soil affects the behavior of fertilizer nitrogen as well as native soil nitrogen. The unique reactions undergone by nitrogen in flooded soils result in considerable loss of applied nitrogen fertilizer; the utilization of added nitrogen generally is poorer in flooded soils than in well-drained soils.

Microorganisms in the denitrification process convert nitrate and nitrite forms of nitrogen to gaseous forms of nitrogen that are unavailable to plants. Because of reduced conditions in the soil, mineralization of organic nitrogen does not proceed past the ammonium stage. The lack of nitrate in a submerged soil does not appear to affect wild rice adversely, since ammonium forms of nitrogen can be utilized equally well by the plant.

Waterlogging affects phosphate solubility and availability to the plant. Saturation of the soil with water increases the availability of soil phosphorus due to conversion of ferric phosphate to the more soluble ferrous form.

Potassium is affected less by submergence of the soil than are phosphorus and nitrogen. Flooding results in a larger fraction of the potassium ions being displaced from the exchange complex into solution. An increase in the concentration of potassium in soil solution should result in greater availability to the crop, but it also could result in greater leaching loss of potassium, particularly in organic soils.

The solubilities of calcium and magnesium are changed only slightly by flooding, but those of iron, manganese, and sulfur greatly increase. The solubility and availability of boron and molybdenum (possibly copper and zinc) should increase slightly in flooded soils.

The wild rice plant has a relatively high requirement for plant nutrients to produce a pound of dry matter (Oelke et al. 1982; Grava and Raisanen 1978). Of the total nutrients in the plant (see Table 2), the grain contains 37% of the nitrogen, 22% of the phosphorus, and 3% of the potassium. Nearly 40% of the nitrogen, 60% of the phosphorus, and 85% of the potassium remain in the stems.

The accumulation of nitrogen, phosphorus, and potassium by the wild rice plant in relation to the accumulation of dry matter is illustrated in Figure 14. During the vegetative growth phase, wild rice grows rather slowly. At jointing, less than 12 percent of total dry matter is produced. Most growth and dry matter production occurs during the reproductive phase. Thirty percent of the growth occurs over a 10-day period from boot stage to early flower. The remaining 50% of dry matter is produced during the last 30 days from mid-flowering to maturity. Under favorable conditions, most of the grain is produced during a 15-day period.

Table 2. Plant nutrients in grain, leaves, and stems of a 2000-pound (dry weight) wild rice crop.

Plant Nutrient	Kilograms/Hectare
Nitrogen	118
Phosphorus	42
Potassium	291
Calcium	294
Magnesium	120
Iron	2
Manganese	2
Zinc	0.6
Aluminum	0.6
Boron	0.1

Nitrogen uptake by the plant occurs in three distinct steps. (See Figure 14.) During the vegetative growth phase, the plant accumulates 30% of its total nitrogen. From boot to early flower, 50% of total nitrogen is accumulated within a 10-day period. During flowering and grain formation, the remaining 20% of nitrogen is taken up. Consequently, the requirement for nitrogen is great during the reproductive phase of growth. The effectiveness of topdress nitrogen application at jointing in commercial fields, observed in the field, is explained partially by the fact that wild rice accumulates 70% of its total nitrogen during flowering and grain formation.

The accumulation of phosphorus and potassium by the plant also follows a stepwise pattern. Accumulation of nitrogen, phosphorus, and potassium continues at a relatively rapid rate until maturity.

Plant analysis is a diagnosis technique used to determine the nutritional needs of wild rice by using the plant itself as an indicator. It involves taking a leaf or some other plant part and determining how much of several essential nutrients it contains. By comparing the results with the amount of each element a normal plant should have, it can be determined whether the sampled plant is getting too much or too little of any nutrient. Table 3 shows the range in concentration of various plant nutrients in wild rice grown in properly fertilized conditions.

Table 3. Concentration of plant nutrients in the dry matter of the second leaf of wild rice at jointing.

Plant Nutrient	Range in Concentration
	Percent
Nitrogen	2.73-3.83
Phosphorus	0.31-0.63
Potassium	2.43-4.31
Calcium	0.26-0.54
Magnesium	0.11-0.16
	Parts/Million
Manganese	80-770
Iron	62-430
Zinc	7-64
Boron	5-9
Copper	1-4
Aluminum	12-160

When sampling wild rice for plant analysis, the second leaf (most recently fully expanded leaf blade) should be collected from 20 plants at the jointing stage. The plant samples should be dried in an oven at 66°C to 79° C for 48 hours, or air-dried in a well-ventilated room for four days. Several

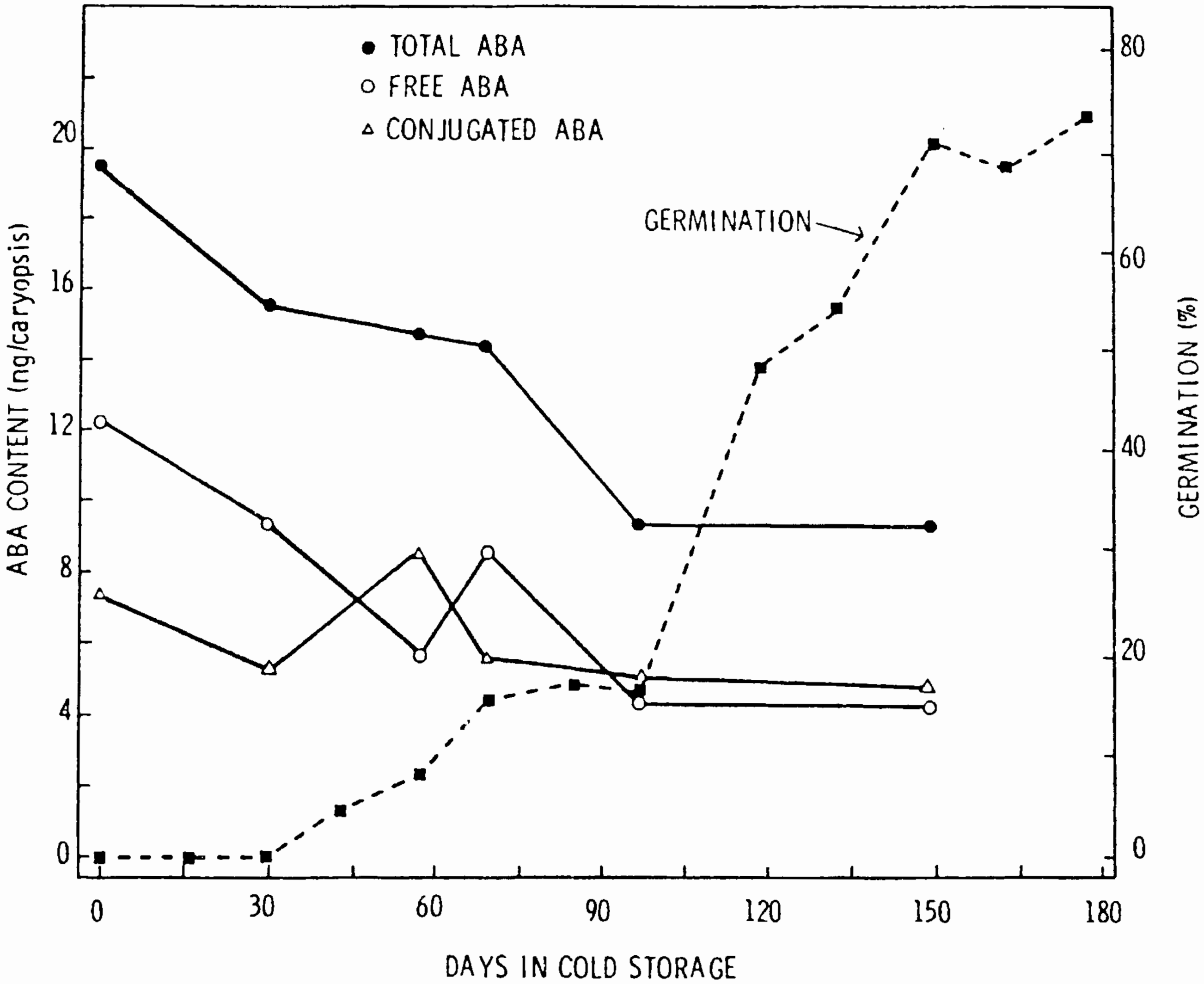

Figure 15. Germination percent and abscisic acid (ABA) content of wild rice caryopses as affected by length of time in cold (2.2° C) water storage.

commercial laboratories are providing analytical services.

WILD RICE SEED PHYSIOLOGY

Seeds of *Z. palustris* will not germinate for at least three months after reaching maturity, even if environmental conditions are satisfactory for growth. An after-ripening period is required in water at freezing or near-freezing temperatures (1.7°C) before the embryo releases dormancy and germination can occur (Simpson 1986). This seed dormancy may be caused by the impermeable pericarp that is covered by a layer of wax and by an imbalance of endogenous chemical growth promoters and inhibitors (Albrecht et al. 1979). (See Figure 15.) In the spring, seeds start to germinate when the water temperature reaches about 5.5°C. Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo (Cardwell et al. 1978).

Seeds of *Z. aquatica* var. *aquatica* have been found from Florida that have little or no dormancy. These seeds will germinate within 2 to 3 weeks when placed into water at room temperature right after harvest from the panicle. *Z. texana* seeds also don't have much seed dormancy.

The viability of seeds of *Z. palustris* is difficult to maintain for more than one year or even during the three months of cold-water storage. Recent research has shown, however, that seeds can be stored over a longer period when fully hydrated and can tolerate drying and freezing under some conditions (Vertucci et al. 1995).

SUMMARY

There are four species of the genus *Zizania*: *Z. aquatica* and *Z. palustris*, the two annual species, and *Z. texana* and *Z. latifolia*, the two perennial species.

Environmental influences on the development of wild rice (*Zizania* sp) have been investigated at the University of Minnesota since 1972. Although much research was done on plant development before 1972, we have been able to significantly add to our knowledge about the physiology and development of wild rice. Flowering time of *Z. palustris* and *Z. aquatica* is very responsive to day length and temperature. Both species flowered earlier when subjected to short days compared to longer days. Plant size and floret number were reduced when grown with short days compared to longer days. *Z. texana* did not respond as much to day length. The differences in flowering time due to day length were negated by growing the plants at higher temperatures. All flowers in the embryonic state have both male and female primordia, but in most plants, only the male parts develop in the lower part of the panicle and the female (grain) develops in the upper part. In some plants, all flowers develop only female (grain) parts. The wild rice plant has a relatively high requirement for plant nutrients to produce a pound of dry matter. Most growth and dry matter production occurs during the reproductive phase. Pale leaf color during growth is a good indicator of nitrogen deficiency. Seed dormancy may be caused by the impermeable pericarp and by an imbalance of chemical growth promoters and inhibitors. Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo. Seeds can be maintained for viability if dried to a certain moisture level and then stored at temperatures below freezing.

REFERENCES

Aiken SG, Lee PF, Punter D, Stewart JM. 1988. Wild rice in Canada. Publ 1830. Winnipeg: Agric Canada.

Albrecht KA, Oelke EA, Brenner ML. 1979. Abscisic acid levels in the grain of wild rice. Crop Sci 19:671-6.

Bolkhovskidh Z, Grif U, Matvejeva T. 1969. Chromosome numbers of flowering plants. Leningrad: Acad Sci USSR, VL Komerov Bot Instit.

Cardwell VB, Oelke EA, Elliott WA. 1978. Seed dormancy mechanisms in wild rice (*Zizania aquatica*). Agron Journ 70:481-4.

Dore WG. 1969. Wild-rice. Publ. 1393. Ottawa: Can Dept Agric.

Dore WG, McNeill J. 1980. Grasses of Ontario. Mongr 26. Winnipeg: Agric Canada.

Duvall MR, Biesboer DD. 1988. Nonreciprocal hybridization failure in crosses between annual wild-rice species (*Zizania palustris* x *Z. aquatica*: Poaceae). Systematic Bot 13:229-34. Biochem Syst Ecol 17:39-43.

Duvall MR, Peterson PM, Terrell EE, Christensen AH. 1993. Phylogeny of North American oryzoid grasses as construed from maps of platid DNA restriction sites. Am J Bot 80:83-8.

Grava J, Raisanen KA. 1978. Growth and nutrient accumulation and distribution in wild rice. Agron Journ 70:1077-81.

Linnaeus C. 1753. Species plantarum, 1st ed. Stockholm.

Liu Q, Oelke EA, Porter RA, Reuter R. 1998. Formation of panicles and hermaphroditic florets in wild rice. Int J Pla Sci 159:550-8.

Oelke E, Grava J, Noetzel D, Barron O, Percich J, Schertz C, Strait J, Stucker R. 1982. Wild rice production in Minnesota. Publ AG-BU-0546. St Paul: Univ of Minn Agric Ext Serv.

Oelke EA, Jin I. 1994. Wild rice production and plant development research. In: Minnesota wild rice research-1993. Misc Publ 82-1994. St Paul: Univ of Minn Agric Exp Sta.

Simpson GM. 1986. A study of germination in the seed of wild rice (*Zizania aquatica*). Can Journ of Bot 44:1-9.

Vertucci CW, Crane J, Porter RA, Oelke EA. 1995. Survival of *Zizania* embryos in relation to water content, temperature and maturity status. Seed Sci Res 5:31-40.

Warwick SI, Aiken SG. 1986. Electrophoretic evidence for recognition of two species in annual wild rice (*Zizania*, Poaceae). Syst Bot 11:464-73.

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THE ECOLOGY OF "WILD" WILD RICE (*ZIZANIA PALUSTRIS* VAR. *PALUSTRIS*) IN THE KAKAGON SLOUGHS, A RIVERINE WETLAND ON LAKE SUPERIOR

J. Meeker

ABSTRACT

The Kakagon Sloughs are situated on the southern shore of Lake Superior and are unique among the lake's wetlands in their wild rice dominance. In this study, the importance of water level fluctuations for wetland dynamics in Lake Superior was demonstrated for both the region and within the Kakagon. Regionally, mean wetland species richness was greatest along shoreline elevations and declined toward the highest and lowest elevations sampled. In the Kakagon, the vegetational response to water level fluctuations between 1986 and 1989 demonstrated that drawdown years are important in maintaining long-term wild rice abundance by allowing this annual species to rapidly re-colonize areas that were too deep for most aquatic species during the high water years.

At any location in the Kakagon, both channel morphometry and water depth greatly influence the physical environment that developing wild rice plants encounter after germination. In addition, the wild rice plants themselves modify the local environment and greatly influence the sedimentation regime. The data suggest that in many locations along the riverine wetland, the early growth stages of wild rice (the submersed and floating leaf stages) act as filters and trap sediment that then provides the nutrients necessary for the later demanding stages of stem elongation and grain development.

Wild rice productivity was greatest along riverine habitat and at moderate depths in locations just inside the vegetation-open water interface. Most wild rice mortality takes place early on during the submerged leaf stage, as plants are presumably dislodged from the sediment. At the individual plant level, experimental data suggested that there may be a threshold weight for individual plants, below which wild rice mortality is increased.

INTRODUCTION

Wild rice (*Zizania palustris* L. var. *palustris*) is a native North American grain that was once abundant across the "wild rice district" of northeastern Minnesota, northern Wisconsin, and southern Ontario (Jenks 1901). Even though wild rice is now being restored to original levels in many lakes throughout the region (David, this volume), research and restoration on riverine wild rice is less well developed, although it once dominated the shallow margins of gently flowing streams and rivers. In this paper, I will: 1) summarize the taxonomy of wild rice; 2) describe the phenology and life history of wild rice relative to my dissertation research in the riverine habitat of the Kakagon Sloughs; and 3) discuss the ecology of this riverine species based on what is known in the literature and my work in the Kakagon.

THE KAKAGON SITE

The Kakagon Sloughs and their associated wetlands lie on the shores of Lake Superior in northern Wisconsin and are recognized as a National Natural Landmark. The steward of this productive wetland complex is the Bad River Band of Lake Superior Chippewa, who, for centuries, have harvested wild rice from these waters. The research reported here is a response to the Bad River Band's concern for the long-term health of this wetland and the recognized void of information on the ecology of northern wild rice in riverine habitat.

The Kakagon Sloughs are a part of the Lake Superior lowland province and are directly influenced by lakewide water level changes. In addition, this wetland experiences considerable short-term water level fluctuations due to the seiche activity associated with Chequamegon Bay. The Kakagon Sloughs are also unique among Lake

Superior's wetlands in their wild rice dominance. As my dissertation research suggests (Meeker 1993, 1996), both the estuarial characteristics of the Kakagon and the influence of fluctuating water levels on Lake Superior contribute to the wild rice productivity of this wetland.

TAXONOMY

The dynamic taxonomy of the wild rice Genus, *Zizania* is suggested in Table 1a, where authorities have disagreed on the nomenclature of the sub-family and tribe for wild rice. A recent revision of the grass family (Poaceae) has placed *Zizania* in the sub-family Bambusoideae, tribe Oryzeae (Campbell 1985, uncited) and sub-tribe Zizaniinae (Terrell and Robinson 1974). Most treatments recognize four species in the genus *Zizania* (Dore 1969; Warwick and Aiken 1986), two perennial and two annual species. (See Table 1b.) The perennial species occur outside the "wild rice district," one in Asia and the other, an endangered species, in Texas. Both annual species are sympatric; that is, they are both found in the same area, the Upper Midwest. Each species occurs with several varieties. (See Table 1c.) One annual species, *Z. palustris*, can be distinguished from the other, *Z. aquatica*, by its larger edible grain, leathery hulls (lemmas), and hairs on the seed that are restricted to rows over the vascular bundles (Warwick and Aiken 1986; Duvall and Biesboer 1989).

Zizania palustris has two varieties, one I like to call northern wild rice (*Zizania palustris* var. *palustris*), and the other, interior wild rice (*Zizania palustris* var. *interior*). Northern wild rice is distinguished from interior wild rice by its much smaller stature (0.7 to 1.5 m vs. 0.9 to 3.0 m) and smaller leaf width (4 to 14 mm vs. 10 to 30 mm) (Warwick and Aiken 1986). Domestic cultivars used in the paddy industry are thought to be derived from *Z. palustris* var. *interior* (Warwick and Aiken 1986). *Z. palustris* var. *palustris* is the variety found throughout the Kakagon wetland complex, although there are reports that *Z. palustris* var. *interior* was planted near the mouth of the Kakagon River in the late 1930s in an attempt to increase plant yield. I have not been able to positively identify plants that may be of this planting. All discussion of wild rice or northern wild rice throughout this paper will be in reference to *Zizania palustris* var. *palustris*, unless stated otherwise.

PHENOLOGY AND BIOLOGICAL LIFE HISTORY

The following description of the phenology of wild rice relies heavily on repeated visits over six field seasons (1985 through 1990) to several general areas along the Kakagon River. One of these locations is upstream near the Bad River fish hatchery on Little Round River. Wild rice development at this location occurs about 5 to 6 days earlier than at the other location midway down the east fork of Big Round River. (Much farther down river, near the mouth of the Kakagon, wild rice development can be up to two weeks behind these upstream locations in its phenology.) For the description of the phenology presented below, I report the average date of development between these two locations as recorded in 1989. Development is described for wild rice plants at intermediate water depths (about 0.50 m) unless noted otherwise.

Germination/Submerged Leaf/Floating Leaf Stages

Germination of wild rice seed begins immediately at "ice-out," which can vary between early April and early May. For example, in the Kakagon River in 1989, I first observed seeds germinating on April 24. Submerged leaves emerge from the sediment about one week later (May 2). By mid-May, there was a blanket of submerged-leaf plants throughout the riverine habitat of the Kakagon, and floating leaves of wild rice began to appear along the shallow depths. Wild rice development in the Kakagon is earlier than many of the inland lakes of northern Wisconsin, which is directly related to the later "ice-out" dates on the inland lakes. By June 1, most of the wild rice plants in the Kakagon have produced the additional floating leaves, with a few (< 5%) of the shallower water plants beginning to

Table 1. Taxonomic treatments of Zizania.

A) A recent history of subfamily, tribal and subtribal treatments

Authority	Subfamily	Tribe	Subtribe	Genus (#spp)
Hitchcock and Chase (1951)	Festucoideae	Zizanieae	-	*Zizania* (3)
Stebbins and Crampton (1961)	Oryzoideae	Zizanieae	-	*Zizania* (3)
Gould and Shaw (1983)	Oryzoideae	Oryzeae	-	*Zizania* (4)
Campbell (1985)	Bambusoideae	Oryzeae	(3)*	*Zizania* (4)

* Subtribes of Oryzeae (10 Genera, 100 spp.) - (Terrell and Robinson, 1974)
1) Oryziniae- *Oryza, Leersia*
2) Zizaniinae - *Zizania*
3) Luziolinae - *Luziola, Zizaniopsis*

B) Genus Zizania (According to Campbell, 1985 who recognizes 4 species)

A) Perennial (2) - *Z. latifolia* (grisb) Turcz. ex Stapf
Z. texana Hitch.

B) Annual (2) - *Z. aquatica* L.(3 varieties)
Z. palustris L.(2 varieties)
(plus cultivars)

C) Species and varieties (According to Warwick and Aiken 1986)

Z. aquatica		**Z. palustris**	
pistillate lemma papery; sparsely scabrous all over; not used as edible grain		pistillate lemma firm; scabrous only in rows, otherwise lustrous; edible grain	
Large	**Small**	**Large**	**Small**
Z. aquatica L. var. *aquatica*	*Z. aquatica* var. *brevis*	*Z. palustris* L. var. *interior*	*Z. palustris* L. var. *palustris*
	Z. aquatica var. *subbrevis* Boivin		
so. Wis., so. Mi., east coast, south	tidal flats St. Lawrence	w. Canada, n.central U.S.	Mi. UP, no. Wis, ne. Mn, Ont.

show aerial leaves. Natural mortality for wild rice is highest in the submerged leaf stage, with an average of 44% of plants surviving this natural thinning process. The floating leaf stage is also a vulnerable stage; my results show that about 56% of the plants survive the floating stage (Meeker 1993). (See Figure 1.)

Emergent Leaf Stage

By the third week of June, about one-half of the wild rice plants are in an early emergent-leaf stage, varying between 2 and 6 inches above the water's surface. In deeper water, aerial leaf development can be as much as 7 to 14 days delayed. Floating leaves are still present on most of these plants, but many of the earlier submerged leaves have decayed by this time and are not observable.

By June 25, 1989, the primary stems (culms) of the wild rice had begun to elongate up through the protective aerial leaf sheaths. These developing stems were approximately 5 to 25 cm long at this point, still under the water's surface, and only a fraction of the length that they ultimately could achieve (125 to 250 cm). The changing contributions of different structural parts to the total weight of an "average" plant are shown in Figure 2 and are taken from data compiled during the 1988 growing season in the Kakagon Sloughs (Meeker, unpublished data). Prior to stem elongation, an early emergent plant's strength and rigidity is supplied almost exclusively by the turgor provided by the sheaths of the aerial leaves. (Turgor pressure is outward cellular force due to the fact that vacuoles in the cells are saturated with water; this stiffens the cell wall, which cumulatively increases the total plant's strength).

The relative contribution to plant structure by these leaf sheaths decreases with time, suggesting that early plant support is provided in the least "energetic" manner, that is, by cells with high water content, not by cells with increased cellulose content (which would be more costly to the plant). Figure 2 also shows the increasing importance of the more cellulose-rich and costlier stem in providing support after mid-June. It is important to note that the stem elongation takes place *after* an individual plant's floating leaves have reached the water's surface, and presumably these floating leaves transfer a major portion of their accrued photosynthetic gain to rapid stem elongation. This "leaf first, then stem" development is different from many other emergent aquatic plants that develop leaf and stem tissue at the same time. This may be the foremost reason why wild rice, an annual species (relying only on the meager stored resources in its seed), can compete with perennial emergent species that receive much of their early season development from large rhizomatous reserves.

Tillering and Flowering

Tillers (secondary flowering stems) grow out from nodes of the original plant. They are noticeable by mid-June but only by completely uprooting the plant and looking at the start of tiller development from the first node (which is generally under water). By July 15, about 75% of the wild rice stems are in the early flowering stage. Botanically speaking, wild rice is monoecious, in that its sexes are separate but on the same plant. In addition, wild rice flowers protogynously, with the female flowers on each inflorescence borne above and developing before the males. On any individual plant there appears to be little overlap between male and female development, and outcrossing is thought to be the norm (Elliott 1980). Early female flowering is recognized by noting the feathery white stigmas protruding from the protective seed coverings (lemma and palea), and the flowers themselves are just visible sticking up from the protective leaf sheaths. Since the female flowers are small and inconspicuous at this stage, many observers mistakenly believe the male flowers emerge first. Following the ephemeral emergence of the female flowers, the bright yellow male flowers open and disperse their pollen. Pollen viability appears to be negatively correlated with temperature and positively correlated with humidity (Elliott 1980), and fertilization occurs within two hours of pollination (Weir and Dale 1960). Hot, dry days at time of pollen release can hinder fertilization success and reduce later seed set.

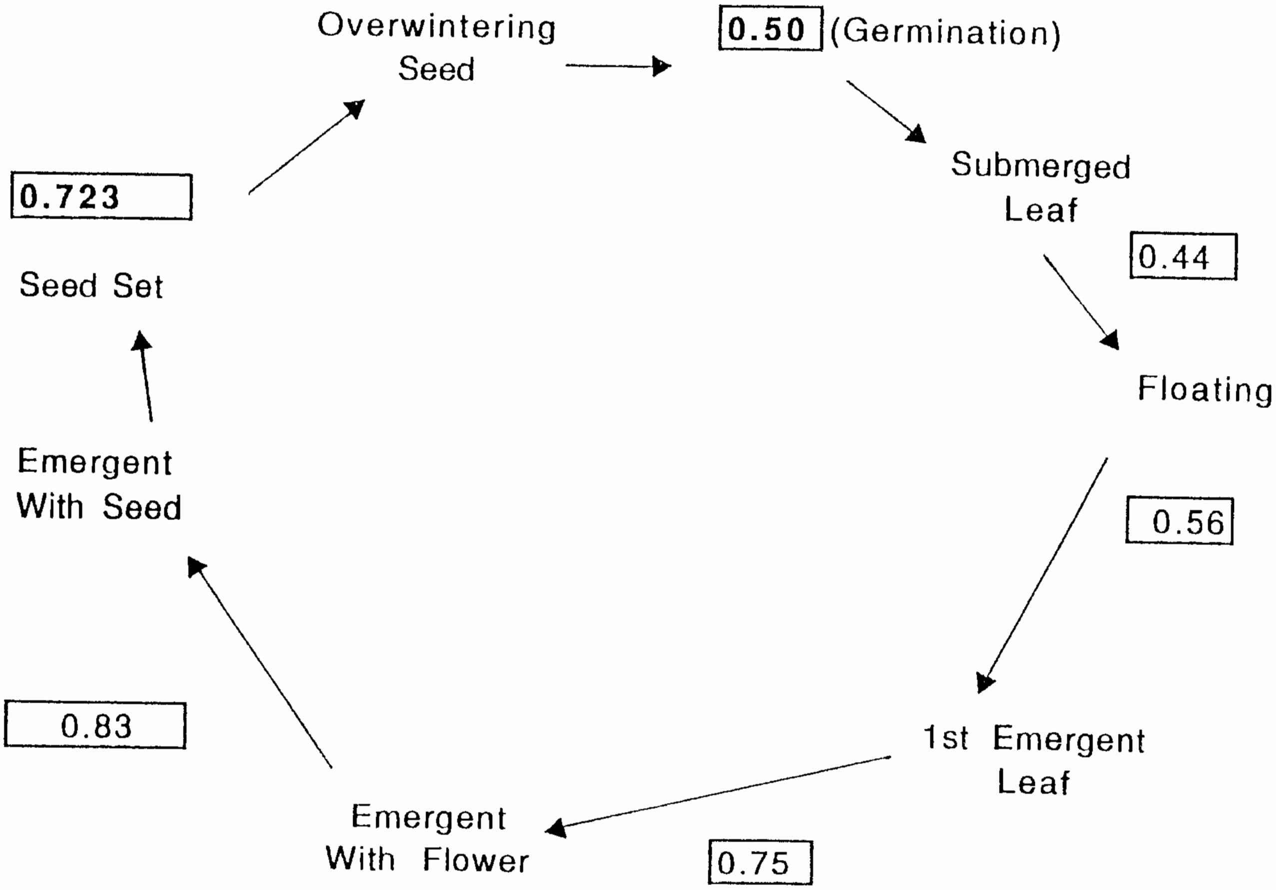

Figure 1. Survivorship for the transition between each of the successive life stages of wild-rice. Numbers in bold-faced type are single estimates, and others are means (n=16).

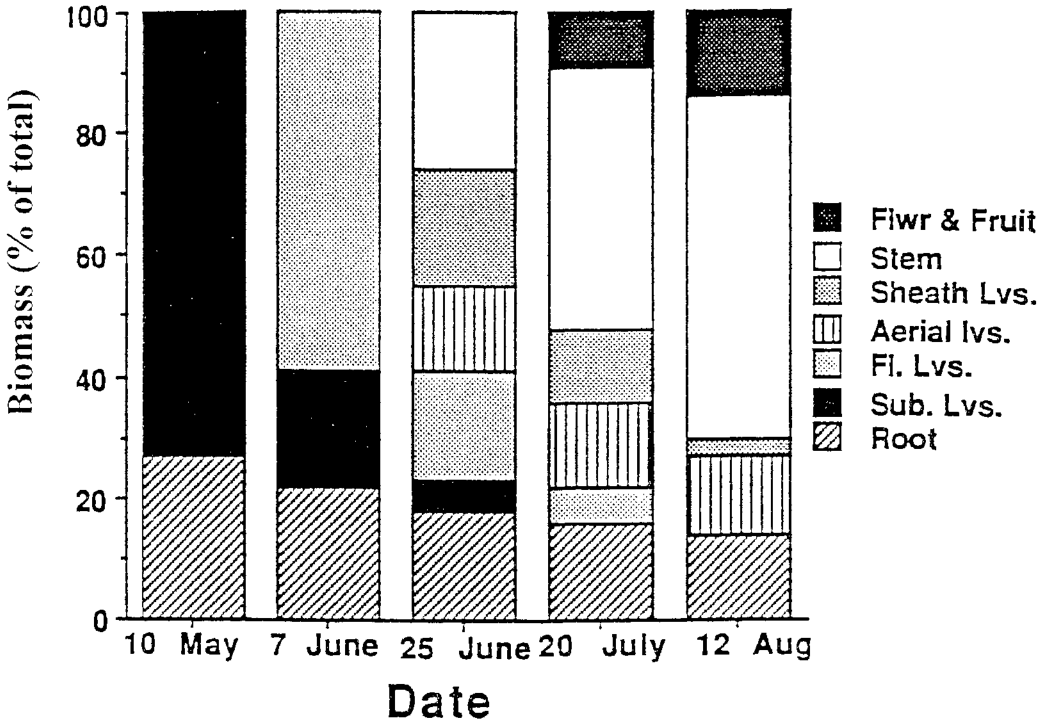

Figure 2. Percent biomass allocated to component parts for representative wild-rice plants sampled over five successive dates, 10 May = submerged-leaf, 7 June = floating-leaf, 25 June = emergent leaf, 20 July = emergent leaf with stem elongation, and 12 August = post-flower and early grain formation. Data are from the Kakagon Slough in 1988.

By mid-July, the tillers are fully emerged and would likely be counted in any estimates of stem density taken at this time. Tillers are 7 to 14 days behind the main stem in their maturity, and, for this reason, contribute to the variability in the final harvest date.

By August 1, the grain on some of the shallow water plants is at the early mature, or "milk" stage, when seed is soft and chewable. Most of the plants are still 2 to 3 weeks behind this early development. The best indication for this early stage of grain formation is the flocking of the black birds that begin feeding on the developing grain (and rice worms, depending on their abundance).

By mid-August, much of the wild rice along the upper stretches of the Kakagon has reached maturity. This is 10 to 14 days prior to maturity in the downstream areas. Hence, the Bad River Natural Resource Department usually opens the ricing season in the Kakagon in two stages. The upper reaches are usually opened by August 15 to 20, with the remaining stands opening one week later. Grain maturity in rice plants is quite noticeable as the plants turn to a buff or straw color as energy is translocated to the developing grain. For an individual wild rice plant, the grain develops and falls (shatters) over a 10- to 14-day period. The research directed toward domestication of wild rice that began in the late 1950s and continued through the 1970s relied upon the discovery of plants that dropped their seed in a more synchronous manner. These semi-"non-shattering" varieties have been the mainstay of the paddy rice industry, now concentrated in Minnesota and California.

Senescence

By mid-September, most of the plants have dropped their seed. Upon dropping, the individual grains readily sink into the water and work their way into soft sediment near the parent plant (Dore 1969). It has been suggested that the retrorse barbs along the long awn of each seed are an adaptation for self burial, where the barbs resist dislodging (Bayly 1983).

Most of the leaves and leaf sheaths have disintegrated by mid-September, though some of the stalks remain erect for a long time. I have seen a number of stalks frozen in the ice, and a small percentage are still erect within the water column at "ice-out" the following season.

Wild rice seed lies dormant in the sediment until the following spring. Typically, about half of one year's seed cohort germinates the next spring (Atkins et al. 1987; Meeker 1993) due to a second dormancy and non-viable seed. Most viable seed germinates in the first year, but about 10% of this seed can remain dormant for up to five years (Meeker, personal communication with P. F. Lee). Both mechanical (pericarp resistance and impermeability) and hormonal conditions (increased concentrations of inhibitory hormones in hulls and pericarp of fresh seed) appear to regulate dormancy in wild rice (Caldwell et al. 1978). The extended dormancy in wild rice is apparently an adaptation allowing the species to survive temporary unfavorable conditions or total crop failures in any given year.

ECOLOGY

Variability in Wild Rice Abundance

Historically, wild rice is known to be quite variable in abundance both temporally and spatially (Moyle 1944; Rogosin 1951; David, this volume). In this context, I refer to temporal variability as the year-to-year change in abundance (i.e., yield, stem density, and acreage) of wild rice at the same location. Spatial variability has two components, including the variability in wild rice over time between any two locations and the variability between any two locations in a given season.

A number of principal ecological factors have been suggested by the literature as being important in the ecology of wild rice and, hence, influencing the variability in wild rice abundance. These factors operate at different scales, and their importance in a riverine environment is, in turn, influenced by differences in channel morphometry and current velocity. The literature does not specifically address the ecology of wild rice in riverine environments; therefore, the relationship between different physical parameters along a river and those known to influence wild rice in the literature are emphasized in the following sections.

Water Chemistry

Studies have investigated the geographic distribution of wild rice with attention given to the possible differences in water chemistry from site to site (Archibold and Weichel 1986; Chambliss 1922). Moyle (1944) suggested that wild rice does not grow in water with greater than 50 ppm sulphate, limiting the westward distribution of wild rice in Minnesota. Other characteristics of water chemistry do not appear to be limiting, as wild rice grows over wide ranges of alkalinity, pH, iron, and even salinity (Rogosin 1951). Much of this early information is still referred to in the literature today (Fannucchi et al. 1986), attesting to its accuracy. However, knowing the variability of wild rice, it also attests to the lack of utility of such measurements in predicting wild rice distributions on a local scale. Large-scale testing of water chemistry in the Kakagon Sloughs, including PH and specific conductivity (Meeker, unpublished data), has indicated some variability over a wide area but does not appear to be an important factor in wild rice distribution in this system.

Disturbance

Disturbance has also been suggested as important in rice ecology (Rogosin 1951). Dore (1969) relates the classic story of a pilot who, while flying, frightened a moose that was feeding in a thick stand of perennial aquatic vegetation. The moose ran off, cutting a wide swath in the perennial vegetation that was colonized in the following year by a dense stand of wild rice. Similar "openings" of the habitat can result from ice scour (Dore 1969). Burial of wild rice in highly flocculant sediment is offered by Lee (1986b) as a key problem in attempting to colonize lakes presently void of wild rice.

I investigated the effects of both sediment and thatch burial on wild rice emergence in the Kakagon by manipulating levels of thatch accumulation and sediment thickness by planting wild rice in a number of "cribs" at contrasting levels of thatch and sediment burial.

Seed burial under 8 cm of sediment resulted in almost a complete absence of emerging seedlings across both depths, whereas plants developing under moderate and no sediment burial showed about a 20 to 30% survival (Meeker 1993). (See Figure 3.) Thatch burial also reduced emergence, but not as dramatically as sediment burial.

Other disturbances in wetlands include annual water level fluctuations, which are discussed in the Water Depth section. It should be noted here, however, that in Great Lakes wetlands, water level changes are necessary to maintain wetland viability. They are thought to be necessary for long-term wild rice productivity in the Kakagon Sloughs, as discussed in the Competition section (Meeker 1993).

Water Depth

Much of the year-to-year variability in wild rice abundance has been correlated with the "within season" fluctuations in water levels (Thomas and Stewart 1969; Stephenson and Lee 1987; Lee 1986b; Pip and Stepaniuk 1988). Rogosin (1951) suggests that increases in water level lower light penetration, which then directly reduces the plants' capability to reach the surface and begin photosynthesizing as a floating leaf and emergent plant. Much anecdotal evidence suggests that rapid water level changes can destroy whole crops by uprooting vulnerable floating leaf plants or by drowning plants after the floating leaf stage (Fannucchi et al. 1986; Lee 1986b).

Water level gradients in both rivers and lakes most certainly influence wild rice abundances (Thomas and Stewart 1969; Dore 1969), creating increased spatial variability. Oelke et al. (1982) suggests, for example, that the maximum depth for the growth of paddy wild rice is about 36 inches (0.91 m), whereas, others (Fannucchi et al. 1986; Dore 1969)

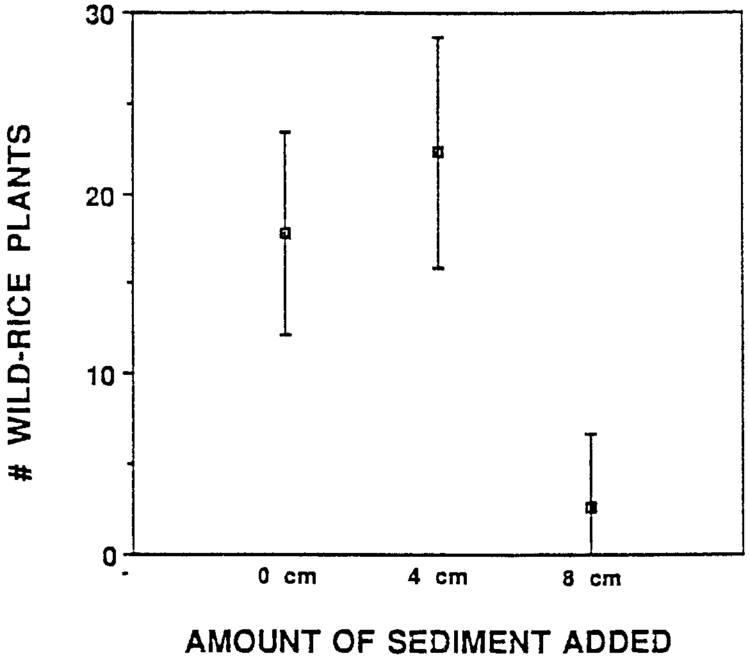

Figure 3. Final number of wild-rice plants remaining from a cohort of 100 wild-rice seeds planted in experimental cribs under 3 levels of sedimentation. Each point represents a mean over 2 depths (n=4). Errors indicate 95% confidence intervals.

report the range of depths for wild rice to be between 6 and 30 inches (0.15 and 0.76 m). I found that the optimal depths for wild rice development fell between 13 and 45 inches (0.35 and 1.1 m) (Meeker 1993), but this range was also much influenced by the location along the riverine habitat (channel morphometry, discussed below). Curiously, it should be noted that southern wild rice (*Zizania aquatica*) is able to flourish in presumably nutrient-rich tidal environments with considerable diurnal changes in water level (Chambliss 1922; Ferren and Good 1977).

Substrate Quality/Nutrient Analysis

Substrate differences and nutrient availability have also been suggested as a major determining factor in wild rice spatial variability (Day and Lee 1989; Lee and Stewart 1983). Fannucchi and others (1986) summarize the literature when they suggest that the ideal substrate for wild rice is about 18 inches (about 45 cm) of soft muck sediment (Dore 1969). Recent research has concentrated on efforts to determine the suitability of specific lake environments for establishing wild rice stands. In this context, environmental regions within lakes have been correlated to an extent with wild rice densities (Lee 1986a). In one case, wild rice was found to be in positive association with a specific pondweed species (*Potamogeton robbinsii*), which, it was suggested, had ameliorated the site to the benefit of wild rice (Day and Lee 1989).

Nutrient analysis of wild rice in agricultural situations (rice paddies) has been studied relative to fertilizer treatments (Grava and Raisanen 1978), but less so in natural settings. In one example of a natural stand nutrient study, Lee and Stewart (1983) were not able to establish good correlations between nutrient uptake and nutrient concentrations in the sediment. Barko and Smart (1986) have suggested that, in general, attempts to relate aquatic plant productivity to sediment nutrients on a mass basis may be more meaningful. They have shown, for example, decreased productivity in submergent aquatic species in highly organic soils (less dense sediment) and suggest that greater diffusion distances required for nutrient uptake in flocculent settings as possible reasons for these findings. These findings may also explain the general lack of success in restoration of wild rice in more flocculent sediment (David, this volume).

Hydrology and Sediment Flux (as It Is Affected by Channel Morphometry)

Another abiotic factor that has been suggested in the literature as being important in influencing wild rice abundance is related to the hydrology of the wild rice habitat. Much of the traditional literature (Jenks 1901; Moyle 1944; Rogosin 1951; Dore 1969) suggests that an ideal habitat for wild rice consists of "slowly moving waters," suggesting that an influx of sediment may be important in creating optimal wild rice habitat (Dore 1969). Lake habitat, without a source of nutrient-rich sediment, may be expected to deteriorate over time. Indeed, it has been noted that newly established stands lose vigor over time (Peden 1982; Keenan and Lee 1988), suggesting that wild rice may mine the substrate much like many annual agriculture crops.

At any specific location in the Kakagon, both channel morphometry and water depth greatly influence the physical environment that developing wild rice plants encounter after germination. In addition, the wild rice plants themselves modify the local environment and greatly influence the sedimentation regime. Seasonal sedimentation rate was seen to vary among four locations that differed in their channel morphometry. Sedimentation was greater in riverine areas compared to the backwater and also differed among the growth stages of wild rice (Meeker 1996). The data suggest that in many locations along the river, the early growth stages of wild rice (the submersed and floating leaf stages) act as filters and trap sediment that then provides the nutrients necessary for the later demanding stages of stem elongation and grain development. Annual cycles of maximum wild rice stand growth immediately follow the import of sediments and their associated nutrients, as suggested by changes in growth allocations of wild rice over time. (See Figure 2.)

Wild rice productivity was also directly related to differing channel morphometry and seasonal sedimentation rate in the Kakagon Sloughs. (See Figure 4.) Peak stand biomass (>400gm $-m^2$ dry weight) and seed yield (> 2000 m^2) were found at intermediate depths in areas with high annual sediment input. In general, there was less biomass and seed yield in backwater areas with little annual sediment input. Wild rice stem density varied greatly among sites and locations along the depth profiles. This was true even for areas with similar total biomass, as some stands had "many, smaller plants" while others had "fewer, larger plants." Dense wild rice populations having many, small plants may act as deterrents for colonization by competing species. suggesting techniques for restoring riverine wild rice.

Competition

Although the literature makes abundant reference to the fact that wild rice faces stiff competition from other aquatic macrophytes (Dore 1969; Rogosin 1951; Lee 1986b; Fannucchi et al. 1986), most of the discussions are post hoc. Observations between 1986 and 1987 in the Kakagon Sloughs suggest individual species' phenology may play important roles in long-term competitive interactions. Yellow water lily (*Nuphar variagata)* for example, sets its fully expanded leaves on the water's surface 7 to 10 days prior to wild rice reaching the floating leaf stage, suggesting a significant interspecific competition for light. Other floating leaf taxa such as several species of *Potamogeton* do not appear to interfere with wild rice in light gathering at an early stage at water depths less than 1 m but do appear to occupy areas deeper than 1 m in wild rice areas. Finally, submerged species have been suggested to be major competitors with wild rice (Lee 1986b). In the Kakagon Sloughs, however, these species appear to occupy areas that wild rice is precluded from due to excess thatch or sediment build-up (Meeker 1993).

In the Kakagon, direct competition experiments were conducted between wild rice and yellow water lily by both planting rice under different levels of lily cover and simulating lily cover over existing wild rice stands. The results indicate that competition with water lily did not affect emergence (as was expected), yet reduced final survival, especially at greater water depths. Within each level of lily competition, wild rice survival was less in deeper water. (See Figure 5.) The competition experiment data suggest that there may be a threshold weight for individual plants, below which wild rice mortality is increased.

In addition to direct competition studies, I monitored for presumed competitive interactions by monitoring for changes in percent cover of wild rice and other macrophytes in response to more than four years of water level fluctuations in Lake Superior. This period of study followed a water level drawdown of about 0.50 m between 1986 (a high water year) and 1988 (a low water year) (Wilcox et al. 1992). Data demonstrates that drawdown years, like 1988, are important in maintaining long-term wild rice abundances by allowing this annual species to rapidly re-colonize areas that were too deep for most aquatic species during high water years. (See Figure 6.) It is suggested that regulation of water levels in the Lake Superior basin toward a more stabile water level regime would be very damaging for this productive wild rice wetland.

SUMMARY

Although the above mentioned factors are recognized as important in influencing the abundance and distribution of wild rice, the literature does not specifically address the ecology of wild rice in riverine environments. In river habitats, a number of the factors listed above (e.g., substrate quality, disturbance, and competition) are influenced by differences in channel morphometry and current velocity.

In general, wild rice is well adapted to the riverine environs. As an annual plant competing with perennials, it benefits from moving waters through both the seasonal pulse of sedimentation and the scouring action or opening of habitat. In addition, annual water level fluctuations appear to favor wild

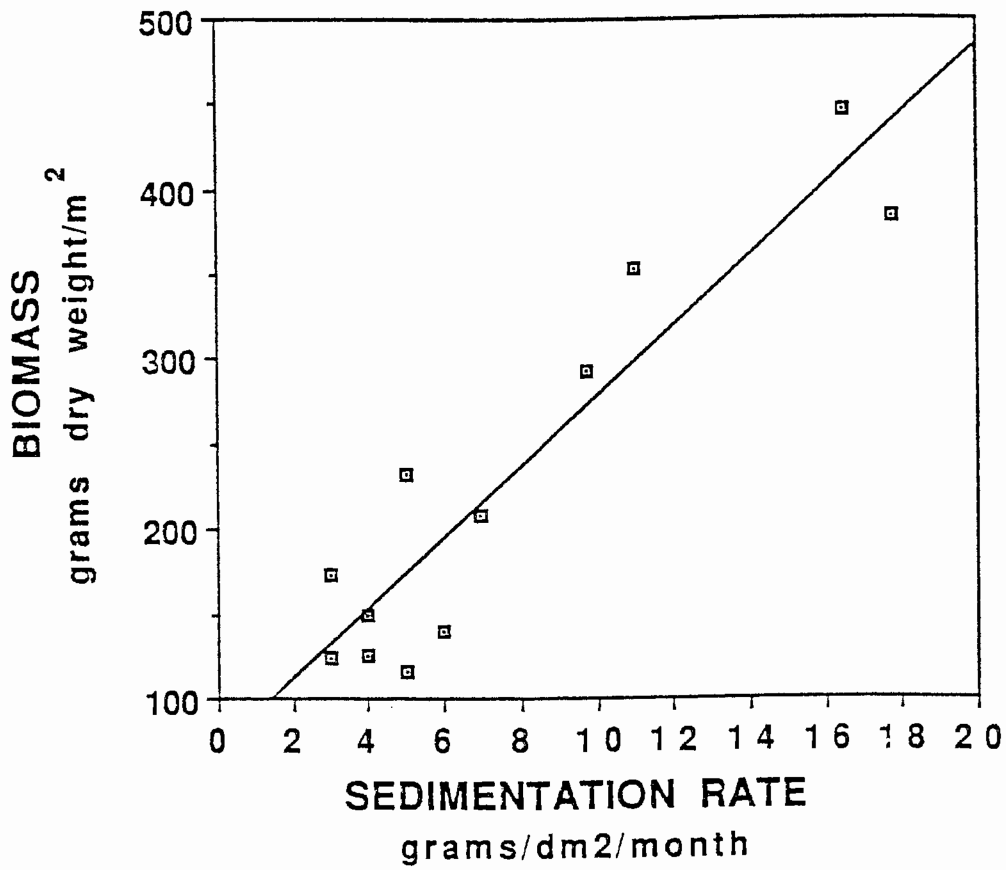

Figure 4. Final biomass (g dry-wt m^{-2}) on August 10, 1989 vs. sedimentation rates (g dm^{-2} mo^{-1}) during the 1989 field season. Regression equation is y = 69.45 + 20.20x, R^2 = 0.86, p>.05.

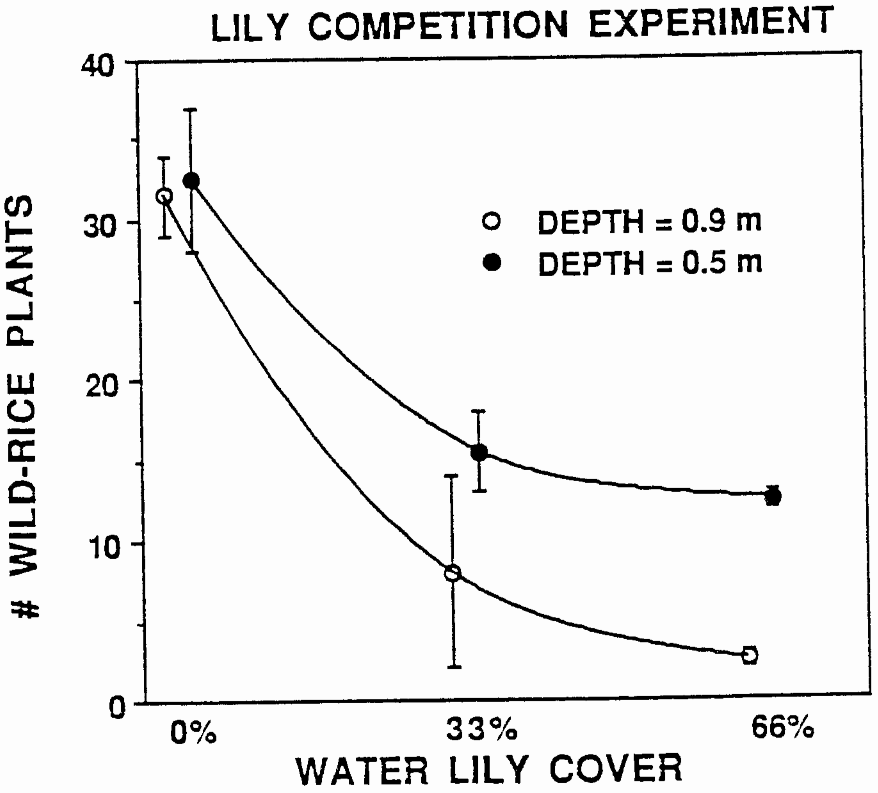

Figure 5. Final number of wild rice plants remaining from a cohort of 100 wild rice seeds planted in experimental cribs under three levels of competition. Planting occurred at 2 depths, 0.9 m (open circles) and 0.5 m (closed circles). Error bars indicate the range of 2 replicates for each point.

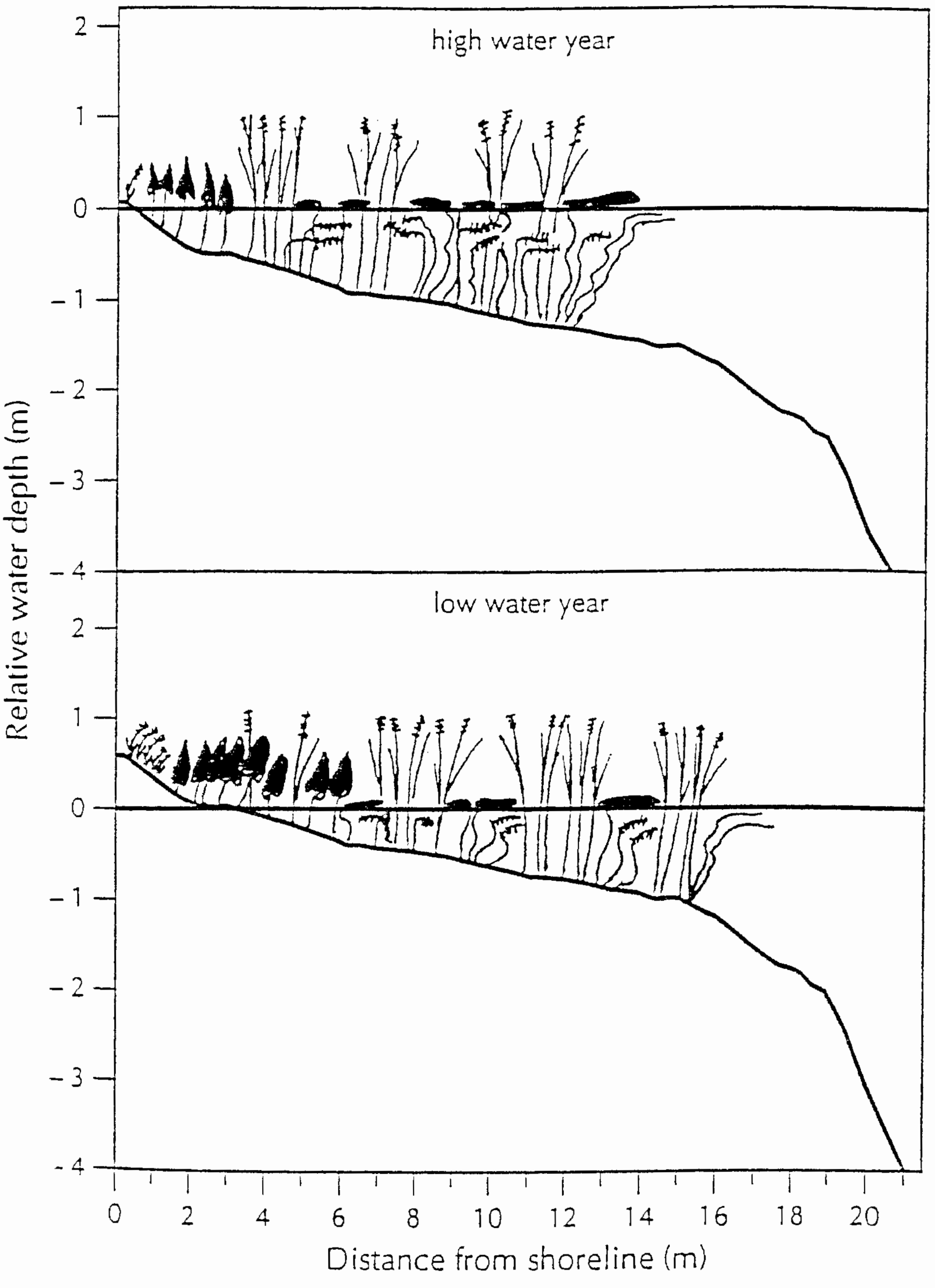

Figure 6. Schematic of a dynamic pattern of macrophyte distribution in a representative profile of a Kakagon River transect depicting changes from (a) high water year to (b) low water year. Drawing is based on actual cover data for 1986 (a) and 1988 (b).

rice productivity in the long term. In contrast to the generally accepted view that stabile water favors wild rice, flooding events, although damaging to wild rice in a given season, act to set back perennial competition and offer a more open habitat for wild rice re-colonization during the subsequent drawdown years. Restoration and management that recognizes these natural processes will likely be sustainable.

REFERENCES

Archibold OW, Weichel BJ. 1986. Variation in wild rice (*Zizania palustris*) stands across northern Saskatchewan. Can Bot 64:1204-11.

Atkins TA, Thomas AG, Stewart JM. 1987. The germination of wild rice in response to diurnally fluctuating temperatures and after-ripening period. Aquat Bot 29:245-59.

Barko JW, Smart RM. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67:1328-40.

Bayly IL. 1983. The caryopsis as a support organ for germinating wild rice, *Zizania aquatica*. Can Field-Naturalist 98(3):369-70.

Caldwell VB, Oelke EA, Elliott WA. 1978. Seed dormancy mechanisms in wild rice (*Zizania aquatica*). Agron J.70(6):481-4.

Chambliss CE. 1922. Wild rice. U. S. Dept Ag Circ 229, 16pp.

Day WR, Lee PF. 1989. Ecological relationships of wild rice, *Zizania aquatica*. 8. Classification of sediments. Can J Bot 67:1381-6.

Dore WG. 1969. Wild rice. Canada Dept Ag Res Publ 1393:1-84.

Duvall MR, Biesboer DD. 1989. Comparisons of electrophoretic seed protein profiles among North American populations of *Zizania*. Biochem Syst Ecol 17(1):39-43.

Elliott WA. 1980. Wild rice (*Zizania aquatica*). In: Fehr WA and Hadley HH eds. Hybridization of crop plants. Crop Science Society of America, pp. 721-31.

Fannucchi GT, Fannucchi WM, and Craven S. 1986. The ecology of wild rice. Univ Wis Ag Ext Service.

Ferren RR, Good RE. 1977. Habitat, morphology and phenology of southern wild rice (*Zizania aquatica*) from the Wading River in New Jersey. Bull Torrey Bot Club 104:392-6.

Gould FW, Shaw RB. 1983. Grass systematics. College Station: Texas A&M Univ Press.

Grava J, Raisanen KA. 1978. Growth and nutrient accumulation and distribution in wild rice, Agron J 70(6):1077-81.

Hitchcock AS, Chase A. 1951. Manual of the grasses of the United States, 2nd ed. U. S. Dept Ag Misc Publ No 200.

Jenks AE. 1901. The wild rice gatherers of the upper lakes: a study in American primitive economics. Washington: Government Printing Office.

Keenan TJ, Lee PF. 1988. Ecological relationships of wild rice, *Zizania aquatica*. 7. Sediment nutrient depletion following introduction of wild rice to a shallow boreal lake. Can J Bot 66:236-41.

Lee PF, Stewart JM. 1983. Ecological relationships of wild rice, *Zizania aquatica*. 2. Sediment-plant tissue nutrient relationships. Can J Bot 61:1775-84.

Lee PF. 1986a. Ecological relationships of wild rice, *Zizania aquatica*. 4. Environmental regions within a wild rice lake. Can J Bot 64(9):2037-44.

Lee PF. 1986b. Summary report: the aquaculture of wild rice. In: Proceedings from Wild Rice, the Natural Crop Conference. May 13-15, 1986; Minaki, Ontario.

Meeker JE. 1993. The ecology of "wild" wild rice (*Zizania palustris* var. *palustris*) in the Kakagon Sloughs, a riverine wetland on Lake Superior [PhD dissertation]. Univ of Wis-Madison.

Meeker JE. 1996. Wild rice and sedimentation processes in a Lake Superior coastal wetland. Wetlands 16(2):219-31.

Moyle JB. 1944. Some chemical factors influencing the distribution of aquatic plants in Minnesota. Am Midl Nat 34:402-20.

Oelke EA, Grava J, Noetzel D, Barron D, Percich J, Schertz C, Strait J, Stucker R. 1982. Wild rice production in Minnesota. Extension Bulletin 464. Univ of Minn, Ag Ext Service.

Peden DG. 1982. Factors associated with growth of wild rice in northern Saskatchewan. Arctic 35(2):307-11.

Pip E, Stepaniuk J. 1988. The effect of flooding on wild rice, *Zizania aquatica* L. Aquat Bot 32:283-90.

Rogosin A. 1951. An ecological history of wild rice. Minn Dept of Conservation, Div Game and Fish, Sect Res Plan.

Stebbins GL, Crampton B. 1961. A suggested revision of the grass genera of temperate North America. Recent Advances in Bot 1:133-45.

Stephenson S, Lee P. 1987. Ecological relationships of wild rice, *Zizania aquatica*. 6. The effects of increases in water depth on vegetative and reproductive production. Can J Bot 65:2128-32.

Terrell EE, Robinson H. 1974. Luziolinae, a new subtribe of Oryzoid grasses. Bull Torrey Bot Club 101:235-45.

Thomas AG, Stewart JM. 1969. The effect of different water depths on the growth of wild rice. Can J Bot 47:1525-31.

Warwick SI, Aiken SG. 1986. Electrophoretic evidence for the recognition of two species in annual wild rice (*Zizania*, Poaceae). Syst Bot 11(3):464-73.

Weir CE, Dale HM. 1960. Developmental study of wild rice, *Zizania aquatica* L. Can J Bot 38:719-39.

Wilcox DA, Meeker JE, Elias JE. 1992. Impacts of water-level regulation on wetlands of the Great Lakes. Draft Report to the International Joint Commission's Water Level Reference Study Board.

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HEAVY METAL BASELINES FOR WILD RICE FROM NORTH CENTRAL WISCONSIN

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ABSTRACT

Wild rice grain samples from North America have been found to have elevated concentrations of heavy metals, raising concern for potential effects on human health. Wild rice plants growing either in polluted waters or near heavy metal ore bodies in north central Wisconsin could contain elevated heavy metals because of release of metals in area waters and soils. Determining the baselines of heavy metals in various parts of wild rice plants would be useful for biomonitoring these elements in the future. Wild rice plants were collected from four areas in Wisconsin in September 1997 and 1998 and divided into four plant parts for elemental analyses: roots, stems, leaves, and seeds. A total of 194 samples from 51 plants were analyzed across the localities, with an average of 49 samples per plant part depending on the element. Samples were cleaned of soil, wet digested, and analyzed by inductively coupled argon plasma spectrophotometry (ICP) for Ag, As, Cd, Cr, Cu, Hg, Mg, Pb, Se, and Zn. Roots contained the highest concentrations of Ag, As, Cd, Cr, Hg, Pb, and Se. Copper was highest in both roots and seeds, while Zn was highest just in seeds. Magnesium was highest in leaves. Baseline ranges for the 10 elements were established for all plant parts using the 95% confidence intervals of the medians. Using the criteria of highest concentration and lowest confidence interval relative to the median determined that most of the heavy metals are best monitored in the roots. It is also recommended to sample As and Pb in seeds because levels from the localities studied may be elevated. To measure the health of wild rice, it is recommended to sample Zn in seeds and Mg in leaves.

INTRODUCTION

Wild rice, *Zizania aquatica* L., is a staple in the diet of native peoples in the north central United States and has become a central component of Native American identity and culture in the Great Lakes region. Wild rice, or *manoomin* in Ojibwe language, has been endowed with spiritual attributes and is a central theme in legends told by the Ojibwa people. Wild rice has also been recognized as an important factor in European settlement in the Great Lakes region as settlements and fur trading posts tended to be established near the plants' natural stands (Vennum 1988).

Wild rice is recognized as an important factor in the ecology of lakes and streams in the Great Lakes region. It is an important source of food for many species of waterfowl and provides roosting areas for mature birds and brood cover for young birds. Wild rice stands maintain water quality by binding loose soils, retaining nutrients, and reducing wind erosion in shallow lakes.

Today, many historic rice beds have been lost. Wild rice is vulnerable to pollution, boat wakes, exotic species, and changes in water levels. Many water bodies that supported wild rice in the past have been dammed, resulting in the destruction of rice habitat. To address these issues, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) has developed a wild rice management and enhancement program. Wild rice abundance is monitored in northern Wisconsin waters. Cooperating with state and federal agencies, GLIFWC is attempting to protect existing wild rice stands, restore historic rice beds, and introduce wild rice in appropriate habitats.

North central Wisconsin is underlain by massive sulfide ore deposits that are rich in technogenic heavy metals (DeMatties 1990). Wild rice is threatened by possible mineral development of these deposits because these developments have the potential of altering water levels in streams and lakes near the mine site. In addition, massive sulfide mining can produce runoff that contains heavy metals and acids and that may be toxic to wild rice.

Because of the importance of preserving wild rice stands and the health of people who consume its seeds, several studies have explored the levels of contamination in wild rice (Bennett et al. 1999; Nriagu and Lin 1995; Pip 1993). These studies suggest that wild rice accumulates heavy metals within its tissues. It is therefore reasonable to hypothesize that wild rice may be a valuable species to use in biomonitoring efforts aimed at assessing environmental change in lakes and streams located near point sources of pollution. This study presents preliminary baseline contaminant levels for wild rice roots, stems, leaves, and seeds as well as an initial assessment of wild rice as a biomonitor.

MATERIALS AND METHODS

Entire wild rice plants were collected at seed set time (September) in 1997 and 1998 from four localities in northern Wisconsin (see Figure 1): Seeley (Bayfield and Sawyer Counties), Willow Flowage (Oneida County), Crandon (Forest and Langlade Counties), and Port Edwards (Wood County). The first three localities were remote and not close to any point sources, while the last one is 15 km upwind (west) of a chlor-alkali plant, which is the largest atmospheric emitter of Hg in the state of Wisconsin. Nine plants were collected at Seely, 6 at Willow Flowage, 15 at Port Edwards, and 21 at Crandon, for a total of 51 plants. Plants were selected randomly and harvested by digging. The roots were washed in place and again back at the laboratory to remove soil.

The plants were separated into their four parts, stored in brown paper bags, and oven dried at 70° C until a constant weight was obtained. All samples were then ground in a stainless steel Wiley mill and acid digested for analysis by ICP at the University of Wisconsin Soil and Plant Analysis Laboratory for 10 elements: Ag, As, Cd, Cr, Cu, Hg, Mg, Pb, Se, and Zn. Silver, As, Cr, Cu, and Se were not measured in the plants from Port Edwards. All data are expressed on a dry weight basis.

The total potential number of data points was 4 plant parts x 4 localities x 12.2 (average) plants/locality x 10 elements = 1950. However, because of missing plant parts (typically insufficient seed for analysis), one outlier value which was omitted, below detection limit values, and part of the design being incomplete, 1315 data points were available for analysis. Values below detection limits varied considerably between elements (see Table 1). Copper, Mg, and Zn had none; Ag, Pb, and Cd ranged from 5 to 14%; As and Cr averaged 27%; and Hg and Se were both over 50%. A decision had to be made on how to handle the below detection limit (BDL) values for statistical analyses. Miesch (1976) recommends not analyzing variables with BDLs greater than 20%, and replacing BDLs with 0.7BDL for variables that have less than 20% BDLs. Gough and others (1987) dropped variables with more than 33% BDLs, and used the same 0.7BDL replacement value for variables with less than 33% BDLs. Sparling and Lowe (1998) used 0.5BDL for replacement values and a 50% BDL threshold for inclusion. Another study dropped no variables at all no matter how many BDLs, and made the detection limit the replacement value (Mudrey and Bradbury 1993). Newman's theoretical study of BDLs (1989) found that at 50% BDLs the mean can be 40% higher than the true mean for normally distributed data, and less for lognormally distributed data. The mean was only 10% off at 25% BDLs. He recommended a maximum likelihood estimator for replacement values, but 0.7BDL was very close to the mean at low BDLs percentages, which agreed with Miesch (1976). Consequently, for statistical analyses, we did not analyze BDLs for Hg and Se, and substituted 0.7BDL for BDL values for As and Cr. All means and medians reported in the results are based on censored data for all elements. Means and medians for As and Cr based on uncensored data

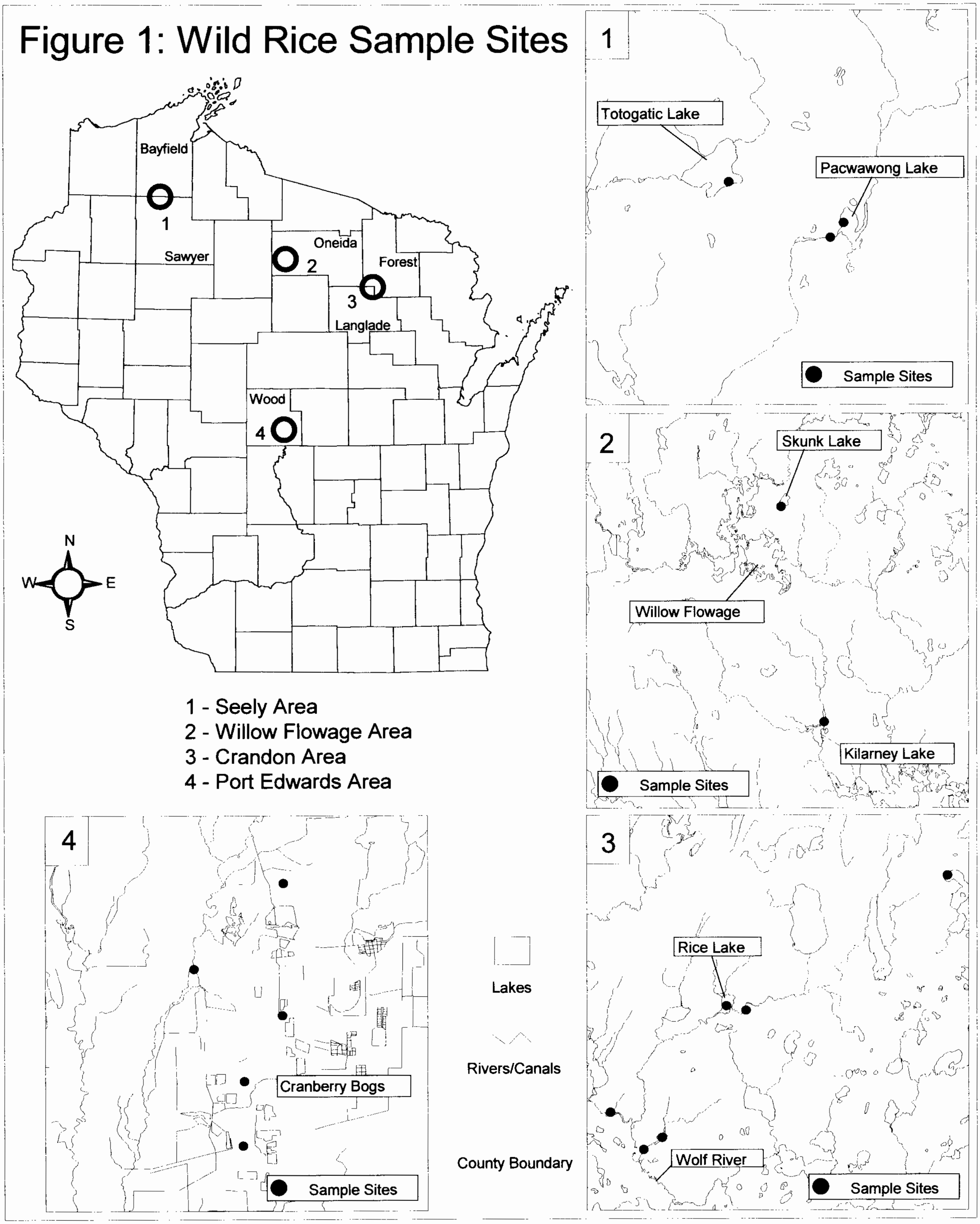
Figure 1: Wild Rice Sample Sites
Bayfield
Sawyer
Oneida
Forest
Langlade
Wood
1
2
3
4
N
S
E
W
1 - Seely Area
2 - Willow Flowage Area
3 - Crandon Area
4 - Port Edwards Area
Totogatic Lake
Pacwawong Lake
Sample Sites
Skunk Lake
Willow Flowage
Kilarney Lake
Sample Sites
Rice Lake
Wolf River
Sample Sites
Cranberry Bogs
Sample Sites
Lakes
Rivers/Canals
County Boundary

(with replacement BDLs) were 10% less than the censored means and medians on average.

Table 1. Below detection limit (BDL) sample numbers for 10 elements in wild rice from northern Wisconsin. Sample numbers are combinations of four plant parts and four localities.

Element	N	BDLs	Total	BDL%
Ag	127	7	134	5
As	97	37	134	28
Cd	166	28	194	14
Cr	99	35	134	26
Cu	134	0	134	0
Hg	64	130	194	67
Mg	194	0	194	0
Pb	180	14	194	7
Se	60	74	134	55
Zn	194	0	194	0
Total	**1315**	**325**	**1640**	**20**

Baselines are presented as 95% confidence intervals of the medians because they are better measures of central tendencies than means for data that are not normally distributed. Confidence intervals of medians and Mood's median significant tests were calculated using MINITAB.

RESULTS

Baseline values are presented for seeds, leaves, stems, and roots in Tables 2 through 5. Baselines are presented as medians +/- the 95% confidence interval of the median, and the interval as a percent of the median as a measure of how large the interval is. The nutritional elements, including Cu, Mg, and Zn, had the lowest variability with intervals between 10 and 30% of the medians. Chromium and Hg had the highest variability with intervals exceeding 100% of the medians depending on plant part. Seeds tended to have the greatest variability, with intervals averaging 57% of the medians. Stems were 40% on average, followed by leaves at 32% and roots were the lowest at 28%. Medians between the four plant parts were all significantly different ($P < 0.001$) for all 10 elements using Mood's median test.

Nine of the ten elements were significantly different between roots, stems, leaves and seeds (Bennett et al. 1999). Six elements were highest in roots: Ag, As, Cd, Cr, Pb, and Se. Copper and Zn were both highest in seeds, followed by roots, and then low in leaves and stems. Lead was almost three times higher in leaves and seeds than in stems, although still much lower than in roots. Magnesium was highest in leaves, followed by roots. Mercury was highest in roots and seeds compared to stems and leaves, although this was not significant at the 0.05 probability level.

Six elements were significantly different between the four localities: Ag, As, Cr, Mg, Pb, and Zn (Bennett et al. 1999). Plants at Crandon and Willow Flowage were highest for As, Pb, and Zn. Chromium and Mg were highest in plants at Crandon, and Ag was highest at Willow Flowage. Port Edwards or Seely generally tended to have plants with the lowest concentrations.

Concentrations of As, Cd, Cr, Mg, and Pb depended on the interaction between plant part and locality. Cadmium in roots was highest at all localities except at Seely, where leaves were higher. Cadmium in seeds and stems did not differ much between localities. Magnesium was highest in leaves at all localities except Crandon, where roots, leaves, and stems all had the same concentration. The highest root concentrations of Pb were found at Crandon and Willow Flowage, but the concentrations at the other two localities still exceeded the other plant parts, which hardly varied across localities at all. The high concentrations in the roots of Ag, As, Cr, Hg, and Se were all at Crandon. The highest concentrations of Cu and Zn in seeds were found at Crandon and Port Edwards.

DISCUSSION

A discussion of the distributions of the 10 elements in the plant parts is available elsewhere (Bennett et al. 1999). Here we will discuss the baseline values.

Table 2. Baselines (ppm) for 10 elements in wild rice seed from northern Wisconsin. Baseline is the 95% confidence interval of the median. The interval as a percent of the median is given in the last column.

Element	N	Lower	Median	Upper	Interval as % of the median
Ag	29	0.003	0.006	0.010	58
As	3	0.018	0.136	0.161	53
Cd	44	0.012	0.016	0.020	25
Cr	29	0.138	0.285	0.590	79
Cu	**29**	**3.18**	**4.15**	**5.80**	**32**
Hg	7	0.010	0.022	0.082	164
Mg	45	1012	1152	1255	11
Pb	44	0.151	0.250	0.371	44
Se	3	0.125	0.146	0.364	82
Zn	**45**	**36.8**	**43.4**	**47.0**	**12**

Table 3. Baselines (ppm) for 10 elements in wild rice leaves from northern Wisconsin. Baseline is the 95% confidence interval of the median. The interval as a percent of the median is given in the last column..

Element	N	Lower	Median	Upper	Interval as % of the median
Ag	33	0.00957	0.0139	0.0162	24
As	33	0.3046	0.51225	0.86021	54
Cd	48	0.02998	0.042	0.0701	48
Cr	33	0.37682	0.6711	1.14862	58
Cu	33	2.11721	2.45418	2.80048	14
Hg	18	0.012	0.016	0.026	44
Mg	**48**	**1855.69**	**2210.28**	**2662.63**	**18**
Pb	48	0.50537	0.743	0.809	20
Se	11	0.2291	0.33297	0.38168	23
Zn	48	8.3	10.6634	12.8311	21

Table 4. Baselines (ppm) for 10 elements in wild rice stems from northern Wisconsin. Baseline is the 95% confidence interval of the median. The interval as a percent of the median is given in the last column.

Element	N	Lower	Median	Upper	Interval as % of the median
Ag	36	0.00667	0.00883	0.0118	29
As	36	0.10252	0.25737	0.38564	55
Cd	51	0.015465	0.021913	0.0308	35
Cr	36	0.007	0.16912	0.39596	115
Cu	36	1.02952	1.30995	1.65584	24
Hg	13	0.011	0.016	0.026	47
Mg	51	997.95	1083	1293.98	14
Pb	51	0.16526	0.221	0.287	28
Se	10	0.19793	0.2829	0.388993	34
Zn	51	11.3951	14.0241	17.407	21

Table 5. Baselines (ppm) for 10 elements in wild rice roots from northern Wisconsin. Baseline is the 95% confidence interval of the median. The interval as a percent of the median is given in the last column.

Element	N	Lower	Median	Upper	Interval as % of the median
Ag	**36**	**0.015**	**0.0189**	**0.0265**	**30**
As	**36**	**4.6637**	**7.1423**	**13.2051**	**60**
Cd	**51**	**0.085**	**0.112499**	**0.153**	**30**
Cr	**36**	**3.1746**	**4.9441**	**6.4698**	**33**
Cu	**36**	**4.06436**	**4.53017**	**5.34216**	**14**
Hg	**26**	**0.0236**	**0.0305**	**0.03772**	**23**
Mg	51	1326.48	1746.5	1945.52	18
Pb	**51**	**3.4587**	**4.0174**	**6.4853**	**38**
Se	**36**	**0.62861**	**0.76265**	**0.91326**	**19**
Zn	51	21.8357	24.1	30.4988	18

Two methods for determining which plant parts to use for monitoring each element include basing it on the plant part that contains the highest concentrations of each element, or basing it on the parts that have the smallest confidence intervals relative to the medians.

Based on using the highest concentrations, seed would be best for sampling and monitoring Cu and Zn. Leaves would be best for Mg, while roots would be best for the other elements tested. Stems did not have the highest concentrations of any elements.

Based on using the smallest confidence intervals, seed would be best for Cr, Mg, and Zn. Leaves would be best for Ag, Cu, and Pb, while roots would be best for As, Cd, Hg, and Se. Stems did not have the lowest confidence intervals for any elements.

These two decision rules agree on Zn in seeds, and As, Cd, Hg, and Se in roots. It doesn't make a lot of sense to measure Mg in seeds when the highest concentration is naturally in the leaves, and the difference in the intervals as percentages is only 7%. Chromium is almost ten times higher in roots than seeds, which makes a compelling case of using roots even though the variability is more than twice that in seeds. Copper has the same level of variability in both roots and leaves, but the highest concentration is in the roots, suggesting that roots be used for Cu. Lead is so much higher in roots than leaves that it is compelling to monitor it in roots even though the variability is higher. Silver is about the same on both criteria in both roots and leaves with roots having a slightly higher concentration. These arguments point to a consensus that using the highest concentrations is the preferred decision rule for deciding on which plant part to use for biomonitoring. For 8 of the elements, roots would be the preferred part, and leaves for Mg and seeds for Zn (shown in bold in Tables 2 through 5).

Two exceptions to this recommendation concern arsenic and lead. Both were found to be elevated in the seed (Bennett et al. 1999). Although the seed concentrations were an order of magnitude lower than the roots, the concentrations were elevated compared to other literature values. Future sampling for arsenic and lead may want to include seed with roots because of this concern.

In conclusion, it appears that biomonitoring certain heavy metals using wild rice plants is possible in north central Wisconsin, and that roots are the best plant tissues to use for measurements. It is also recommended to sample As and Pb in seeds because of possibly elevated levels from the localities studied. To measure the health of wild rice, it is recommended to sample Zn in seeds and Mg in leaves.

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REFERENCES

Bennett JP, Chiriboga E, Coleman J, Waller D. 1999. Heavy metals in wild rice from northern Wisconsin. Science of the Total Environment (in review).

DeMatties TA. 1990. The Ritchie Creek main zone: a lower proterozoic copper-gold volcanogenic massive sulfide deposit in northern Wisconsin. Econ Geol 85:1908-16.

Gough LP, Jackson LL, Peard JL, Engleman EE, Briggs PH, Sacklin JA. 1987. Element baselines for Redwood National Park, California—Composition of the Epiphytic Lichens *Hypogymnia enteromorpha* and *Usnea* spp. Open-File Report 87-169. Denver: U. S. Geological Survey.

Miesch AT. 1976. Geochemical survey of Missouri—Methods of sampling, laboratory analysis, and statistical reduction of data. Geological Survey Professional Paper 954-A. Washington: U. S. Geological Survey.

Mudrey MG, Bradbury KR. 1993. Evaluation of NURE hydrogeochemical groundwater data for use in Wisconsin groundwater studies. Madison: Wis Dept of Natural Resources.

Newman MC, Dixon PM, Looney BB, Pinder JE. 1989. Estimating mean and variance for environmental samples with below detection limit observations. Water Res Bull 25:905-16.

Nriagu JO, Lin TS. 1995. Trace metals in wild rice sold in the United States. Sci Tot Env 172:223-8.

Pip E. 1993. Cadmium, copper and lead in wild rice from central Canada. Arch Environ Contam Toxicol 24:179-81.

Sparling DW, Lowe TP. 1998. Metal concentrations in aquatic macrophytes as influenced by soil and acidification. Water, Air and Soil Pollut 108:203-21.

Vennum T Jr. 1988. Wild rice and the Ojibway people. St Paul: Minnesota Historical Society Press.

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POSTER/ORAL PRESENTATION

FLOODING PRIOR TO THE GROWING SEASON: A POTENTIALLY IMPORTANT FACTOR FOR THE GROWTH OF WILD RICE IN NAVIGATION POOL 8, UPPER MISSISSIPPI RIVER

J. Therese Dukerschein

ABSTRACT

It is well established in ecological literature that pre-growing season disturbances can contribute to the success of opportunistic annuals such as wild rice. Prior to the beginning of the Long Term Resource Monitoring Program's (LTRMP) vegetation monitoring in 1989, archeological studies and field observations indicated wild rice stands occurred in Navigation Pool 8 of the Upper Mississippi River from prehistoric times to as recently as 1984. However, wild rice was seldom observed in Pool 8 between 1989 and 1993. By 1994, following a record summer flood in 1993, LTRMP biologists were able to map more than 300 acres[1] (121.4 ha) of quality (more than 90% cover) wild rice stands in backwaters of Pool 8. Gage data indicate these backwaters are influenced by main channel water level elevations. Feet/day of water exceeding 635.3 ft (193.6 m) for the La Crosse gage of the main channel[2] were calculated for each of 8 pre-growing-season years. Graphs indicate feet/day per year may be correlated with annual acres of quality wild rice stands. Quality stands continued to occur in these backwaters from 1995 to 1997 and ranged from 27 to 119 total acres (10.9 to 48.2 ha). Controlled research and wild rice coverages from backwaters upstream of Pool 8 are needed to reveal mechanisms and to distinguish lag-time due to the large summer disturbance in 1993 from effects of typical spring flooding from 1995 to 1998. Possible flood-related mechanisms could include tillage (suppression of competition from perennials or exposure of buried seed banks) and nutrient dynamics (inflow/deposition of nutrient-enriched sediments).

INTRODUCTION

Archeological studies indicate wild rice was harvested by the Oneota culture in the La Crosse, Wisconsin, area as early as 1300 A.D. (Arzigian et al. 1989). La Crosse is located on the southern edge of Jenks' "wild rice district," but Jenks (1977) indicated it grew in large stands in sloughs along the Mississippi River in the La Crosse area in the 1800s. Low-head navigation dams constructed by the U. S. Army Corps of Engineers in the mid - 1930s raised water levels in the area, altering the historical distribution of wild rice. It is well documented that wild rice does not tolerate changes in water level elevation above 6 inches (15.24 cm) per day during and after the floating-leaf stage of development from mid-June through July (Moyle 1944; Moyle and Hotchkiss 1945; Rogosin 1957; Kahl 1993). In the 1940s, a federal game warden reportedly planted 40 acres (16.2 ha) of wild rice in Blue Lake, an isolated backwater of navigation Pool 8 (Dukerschein, personal communication with S. Allen of Allen's Boat Livery, La Crescent, Minnesota). It is not known whether wild rice was present in Blue Lake prior to this planting or whether it was also planted in other areas of Navigation Pool 8 after the dams were operational.

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[1]Because the U. S. Army Corps of Engineers measures Mississippi River Water Level Elevation and discharge in English measurement units and manages water levels in the river accordingly, primary measurement units in this paper are expressed in English units. For standardization with other scientific literature and for ease of comparison, corresponding metric units have been referenced in parentheses adjacent to the English units throughout the text, except in tables and figures.

[2]Data from U. S. Army Corps of Engineers web site (http://www.mvp-wc.usace.army.mil/projects/Lock8.html).

Wildlife managers on the Mississippi River are interested in monitoring wild rice because of its value as food and/or habitat for waterfowl, muskrats, and water birds. The black tern (*Chlidonias niger*), a bird of particular interest, is federally listed as a species of concern (U. S. Fish and Wildlife Service 1994). Presently, areas that contain wild rice on the Upper Mississippi Fish and Wildlife Refuge are prime brood and/or migration habitat for black terns and many other water birds. These areas are managed to maintain deep-marsh habitat and to minimize human-induced disturbances; no harvesting of wild rice by humans is permitted on the refuge. In 1989 and from 1991 to 1998, Long Term Resource Monitoring Program staff monitored wild rice and other floating-leafed and emergent aquatic plants in the floodplain of Navigation Pool 8 on the Upper Mississippi River Fish and Wildlife Refuge to provide information to state and federal wildlife managers.

Study Area

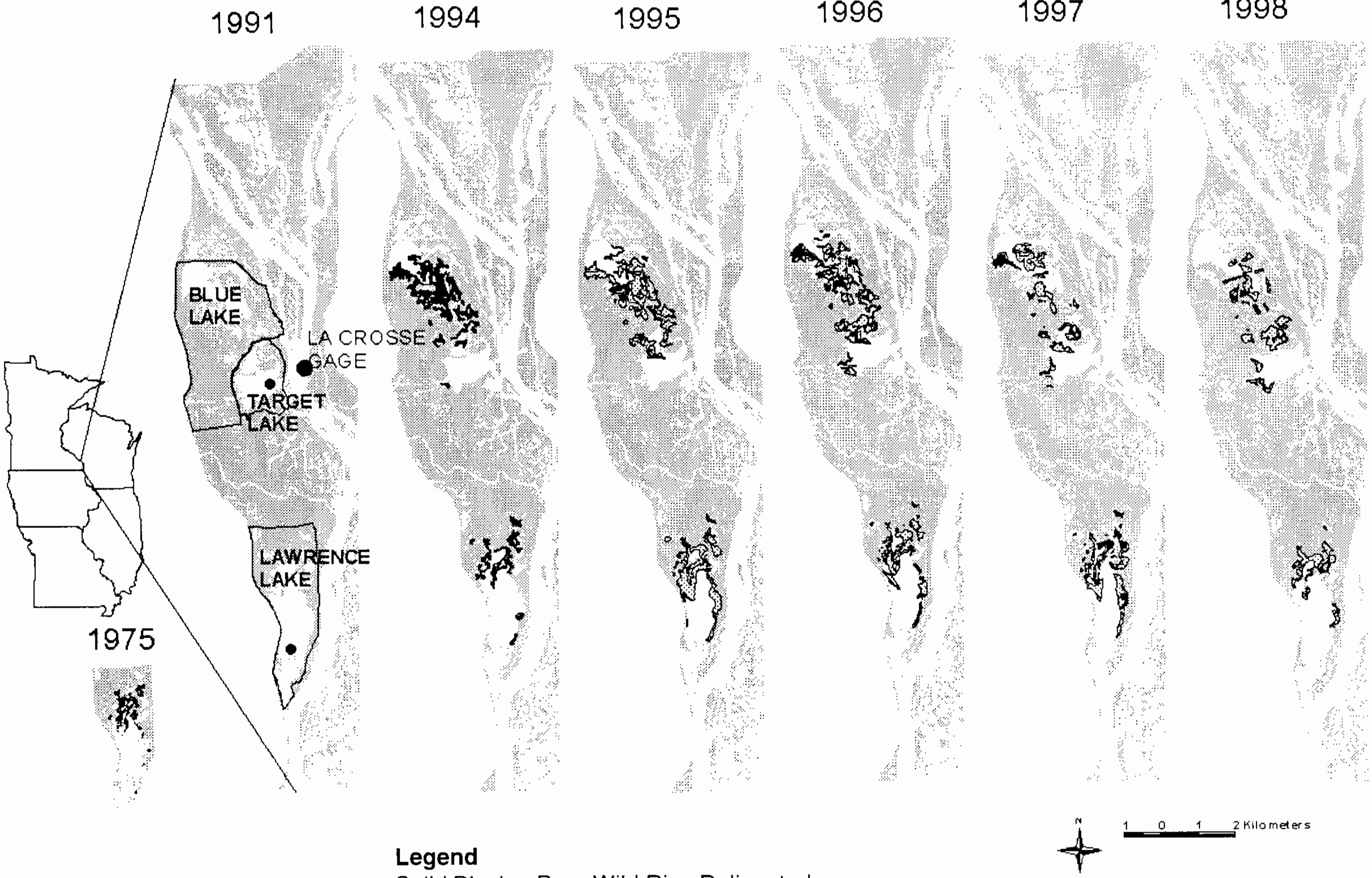
The Upper Mississippi River between St Anthony Falls, Minnesota, and Cairo, Ohio, is divided into a series of navigation pools by 26 consecutively numbered low-head navigation dams. Each pool is numbered the same as the downstream dam that forms the pool. Navigation Pool 8 includes the floodplain between railroad dikes on the Minnesota and Wisconsin sides of the Mississippi River and extends from Lock and Dam 7 at Dresbach, Minnesota, 23.3 river miles (38.8 km) downstream to Lock and Dam 8 at Genoa, Wisconsin. The floodplain varies from 3 to 5 miles (5.0 to 8.3 km) wide and the total area of Pool 8 and its floodplain between railroad tracks contains 38,072 acres (15,408 ha). With the exception of 4 acres (1.6 ha) delineated on the northern edge of Pool 8 in 1994, wild rice has been delineated by Long Term Resource Monitoring staff in three mid-pool backwaters of the Mississippi River located in Minnesota (see Figure 1), and these three backwaters comprise the study area. Blue Lake is an isolated backwater except during seasonal flooding and contains 25 acres (10 ha) of open water at flat pool. Target Lake (194 acres; 78 ha) and Lawrence Lake (206 acres; 83 ha) are contiguous to the main channel of the Mississippi River and have more boating traffic than Blue Lake. A long-term daily water-level elevation gage (the La Crosse gage) is located on the main channel of the Mississippi River adjacent to the La Crosse Municipal Sewage Plant on Isle De La Plume and nearly opposite the mouth of Target Lake. The La Crescent Municipal Sewage Plant discharges into the western portion of Blue Lake. A commercial boat marina is located in Lawrence Lake near the southern end where it joins the main channel of the Mississippi River. Water chemistry in Pool 8 of the Mississippi River is consistently alkaline (Long Term Resource Monitoring Program Water Quality Database, U. S. Geological Survey Upper Midwest Environmental Sciences Center web site, http://www.umesc.usgs.gov/data_library/water_quality/water_quality_page.html).

Study Objectives

The objectives of this study were to:

- quantify existing Pool 8 coverages of wild rice and map distribution through time;
- use existing main channel daily water level elevation data at the La Crosse gage and an estimated flood threshold of 635.4 feet (193.7 m) for the study area to calculate an index that tracks duration and magnitude of flooding above this threshold in each pre-floating-leaf-stage year (The floating-leaf stage was chosen as the division point of the growth year for this study because it is the stage most vulnerable to flooding. The absence of wild rice during exceptional summer flooding in 1993 and the sudden increase in wild rice coverages in 1994 suggested that flooding might be an ecological "switch" with a dual role. Flooding could possibly help the subsequent year's wild rice crop if other requirements were met, but harm the present year's crop if it occurred during the vulnerable floating-leaf stage.);
- compare areas of pure wild rice delineated

Figure 1: Study Area and Distribution of Wild Rice, Pool 8, Mississippi River



Legend
Solid Black = Pure Wild Rice Delineated
Dotted Pattern = Wild Rice Mixed With Other Plants
Grey = Land
White = Water
Black circles = Fixed Water Quality or Gage Sites

to the annual amplitude and duration of water level elevation exceeding the flood threshold; and

suggest flood-related hypotheses if some sort of relationship appears to exist. (For example, flooding prior to a given growth year of wild rice might clean out competition from perennials and encourage wild rice to flourish the following growth year because wild rice is able to survive as dormant seeds for several years.)

METHODS

Coverages

Coverages of wild rice were initially digitized by using ground-truthed and interpreted 1:15,000 color-infrared aerial photography (1:9600 in 1975) registered onto U. S. Geological Survey base maps or digital ortho-quadrangle photographs. Color-infrared transparencies were photographed during peak biomass for most common emergent aquatic plants. Photo dates ranged from July 21 in 1995 (which is on the early side of the ideal window for wild rice) to September 13 and 14 in 1975, which is somewhat late for wild rice. Other years, photographs were taken during August, the best time-window for clear wild rice signatures. The 1975 photographs were interpreted in 1976 according to an older classification scheme, then reinterpreted for Target Lake and Lawrence Lake with the Long Term Resource Monitoring Program's present classification scheme by the Long Term Resource Monitoring Program staff in 1996. Exposures for all photos were good except for 1975, when some underexposure combined with the late date of photography and inability to ground-truth made reinterpretation of the 1975 photos somewhat problematic. The minimum mapping unit was generally one acre; rarely, smaller polygons of wild rice were mapped if clearly delineated. The minimum vegetation coverage mapped was 10%. Canopy closure of the dominant vegetation type in each polygon determined percent coverage (Rogers and Owens 1995). Canopy closure of greater than 90% for wild rice corresponded average densities per transect of 0.6 to 1.4 stems/sq ft (6.3 to 15.4 stems/sq m) (Wisconsin Department of Natural Resources, unpublished data). Coverages were generated in Arc-Info software compiled in Arc-View software.

Calculation of Flood Duration and Amplitude

We used "Indicators of Hydrological Alteration" software to calculate the 20-year (1972-92) mean 30-day maximum flood pulse for the 8:00 A.M. daily elevation at the La Crosse gage. The 30-day maximum flood pulse measures the magnitude of a given year's most extreme flood over a 30-day duration (Richter et. al. 1996). Anecdotal reports and gage readings at a reference site located in Blue Lake indicate that this calculated threshold of 635.3 ft (193.7 m) is a conservative estimate of the flood threshold. It is about 1.3 ft (0.4 m) more than the estimated elevation where water actually flows from Target Lake's elevation into the slightly higher elevation of Blue Lake. Backwater gages in Blue Lake, Target Lake, and Lawrence Lake placed and read by Long Term Resource Monitoring staff in 1993 and 1994 indicate water level fluctuations in these backwaters generally corresponded to main channel water level fluctuations (Dukerschein, personal communication with J. Wlosinski, Upper Mississippi Environmental Sciences Center, U. S. Geological Survey, La Crosse, Wisconsin). During one month in Blue Lake in the summer, however, water was held higher than would be predicted with main channel gages, and we hypothesize that beaver activity might have held water for this transient period, or springs present in Blue Lake might have been discharging proportionally more water when the water table was high and inflows from Target Lake/main channel were decreasing. Missing gage readings at the Brownsville gage [about 1 mile (1.6 km) downstream of the mouth of Lawrence Lake] prevented accurate interpolation at the mouth of Lawrence Lake; the La Crosse gage threshold was used for all backwaters. Feet per year exceeding the flood threshold in growth year 1993-94 were calculated by subtracting 635.3 ft (193.7 m) from June 15, 1993, to June 14, 1994, daily elevations and summing the positive differences. The same procedure was used to calculate growth-year flood index levels for all growth years included in the study.

Water Quality Data

Biweekly water quality data collected from one fixed site each in Target Lake and Lawrence Lake according to standard monitoring procedures (Soballe 1993) was downloaded from the U. S. Geological Survey's Upper Midwest Environmental Sciences Center's web site to examine annual and seasonal trends. Only quarterly data from random sites stratified by aquatic area type (isolated backwater) has been collected for Blue Lake from July 1993 to present. The spring quarter data (April 23 to May 7 1999) was downloaded from the same web site and examined for Blue Lake to estimate temperature, turbidity, dissolved oxygen, and velocity trends in that backwater early in the submersed growth stage of wild rice.

RESULTS AND DISCUSSION

Coverages and Distribution

Long Term Resource Monitoring Program staff delineated no wild rice coverages larger than the minimum mapping unit of one acre in 1989, 1991, 1992, or 1993. Coverages of wild rice increased substantially after flood of 1993. (See Table 1 and Figure 1.) In 1994, wild rice was also observed in the field and delineated on photos in Lawrence Lake, a backwater where it had not been previously observed by Long Term Resource Monitoring Program staff, but had been observed and delineated on photos taken in 1975. (See Table 1 and Figure 1.) With the exception of 4 acres (1.6 ha) on the northern edge of Pool 8 in 1994, wild rice was delineated in only the three western, mid-pool backwaters of Pool 8 (Blue Lake, Target Lake, and Lawrence Lake). It is not known whether wild rice is mainly confined to these backwaters in Pool 8 because of seed bank or habitat limitations. In the three backwaters were it occurred post-1994, pure stands of wild rice were most abundant in Blue Lake in 1994, but as of 1998, pure stands of wild rice had declined in Blue Lake and wild rice cover in general was more sparse. (See Figure 1.) A series of severe wind and rain storms in late June/early July 1998 uprooted wild rice in Blue Lake (Dukerschein, personal communication with R. Nissen, Wisconsin Department of Natural Resources, La Crosse), which is farther from the bluff line and therefore less sheltered from westerly winds than Lawrence Lake. Wild rice appeared to survive best in 1998 in portions of Blue Lake and Target Lake that were relatively sheltered from westerly winds. Where it did grow in Blue Lake in 1998 and 1999, it was often mixed with water lilies and other aquatic plants. The north end of Lawrence Lake contained extensive, dense stands of wild rice in 1999.[3]

Summary of Pool-Wide Trends in Cover

The floodplain of Pool 8 (as defined by railroad dikes on each side of the Mississippi River) contains 38,072 acres (15,408 ha). Land (terrestrial plants and urban development) and open water make up the majority of cover in Pool 8. Even in 1994, the best year of the decade for wild rice, wild rice only comprised 1% of total cover in the floodplain. Over the past decade, emergents appear to be the most stable general class of aquatic plants occurring in Pool 8, with submergent plants, rooted floating-leafed plants, and the combination of the two being more dynamic from year to year. (See Figure 2.) Low water in 1989 and good water clarity probably favored submergent plants and the combination of submergent and rooted floating-leafed plants relative to subsequent years. By 1998, when water clarity in most of Pool 8 had again improved, submergent plants had recovered to amounts found in 1989. However, the combined class of submergent/rooted floating-leafed plants remained the about same as it had since 1991, and total acres containing pure wild rice have decreased since 1994. (See Figure 2.)

[3]Mapping and quantification of wild rice delineated in 1999 was not complete at the time of publication.

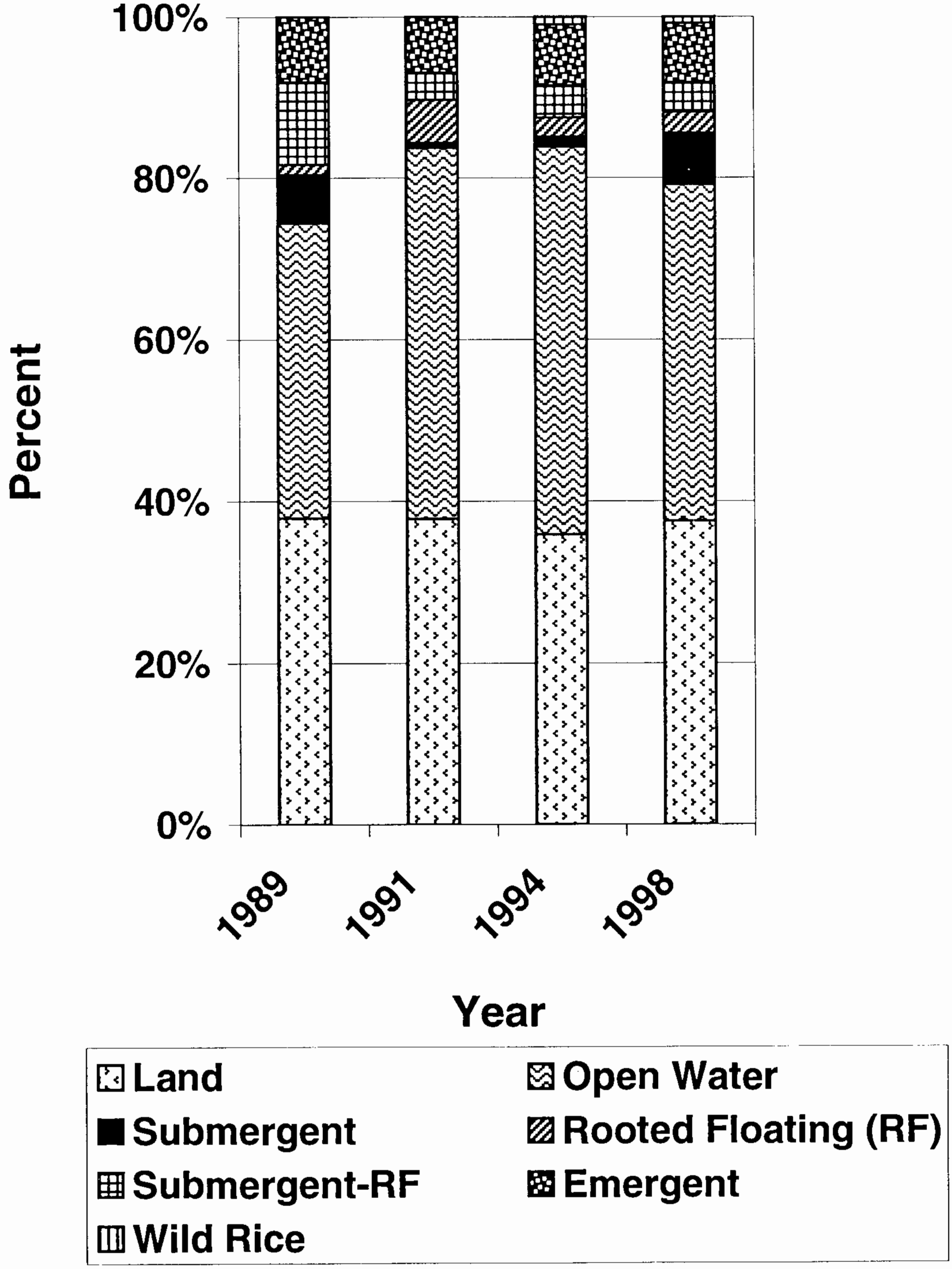
Table 1: Area Comparisons By Year

Wild Rice, Pool 8, 1975, 1989 and 1991-1998

Year	Pure, dense acres	Total pure acres	Mixed acres	Total acres
1975 original PI	_NA*_	_7.6_	_NA_	_25.7_
1975 re-PI	15.2	19.4	55.2	74.6
_1989_	_ND*_	_ND_	_ND_	_ND_
_1991_	_<1_	_<1_	_<1_	_<1_
1992	<1	<1	<1	<1
1993	ND	ND	ND	ND
_1994_	_307.6_	_360.5_	_4.6_	_365.1_
1995	14.5	47.2	515.1	562.3
1996	80	95.7	440.1	535.8
1997	119	161.4	305.2	466.6
_1998_	_17.9_	_26.2_	_168_	_294.2_

*NA = Not Applicable; ND = None Delinated; Italics indicate full-pool coverage

Figure 2: Percent Cover in General Classes, Pool 8



Summary of General Water Quality Trends in Pool 8

Water Clarity

Monthly Licor readings taken throughout the past decade in the main channel at Lock and Dam 8 indicate the 1% transmittance depth of photosynthetically active radiation (PAR) for most years during May and early June when wild rice was in the submergent stage was between 3.3 ft. (1 m) and 4.9 ft. (1.5 m) (Dukerschein, personal communication with J. Sullivan, Wisconsin Department of Natural Resources, La Crosse). However, in 1991, the 1% transmittance depth was less than 3.3 ft. (1 m) and in 1989 and 1998 it exceeded 4.9 ft. (1.5 m). May surface turbidity readings taken biweekly or weekly by Long Term Resource Monitoring Program staff in Target Lake and Lawrence Lake were relatively high in 1992 and 1998 (30 to 40 Nephelometric Turbidity Units/NTUs). Generally, surface turbidities in May at these sites are below 20 NTUs (Long Term Resource Monitoring Program Water Quality Database, U. S. Geological Survey Upper Midwest Environmental Sciences Center web site, http://www.umesc.usgs.gov/data_library/water_quality/water_quality_page.html). Comparison of the 1998 main channel PAR (relatively clear) and the 1998 backwater turbidities (relatively cloudy and taken during a rain event) demonstrates that main channel PAR readings and backwater turbidity readings in open water may not necessarily be consistent with each other, probably due to factors such as different dates/locations of readings, local run-off events, and wind fetch. Areas where wild rice grows in backwaters can easily exceed 3.3 ft (1 m) in depth in May during spring flooding, but no measures of water clarity have been consistently taken in these specific areas.

Water Temperature

The years with the earliest springs and the earliest potential germination windows were 1993, 1994, and 1998, when water temperatures had reached 50°F (10°C) at the backwater fixed sites by the second week in April. The coolest years were 1995, 1996, and 1997, when temperatures at backwater fixed sites reached 50°F (10°C) around May 1 (Long Term Resource Monitoring Program Water Quality Database, U. S. Geological Survey Upper Midwest Environmental Sciences Center web site, http://www.umesc.usgs.gov/data_library/water_quality/water_quality_page.html).

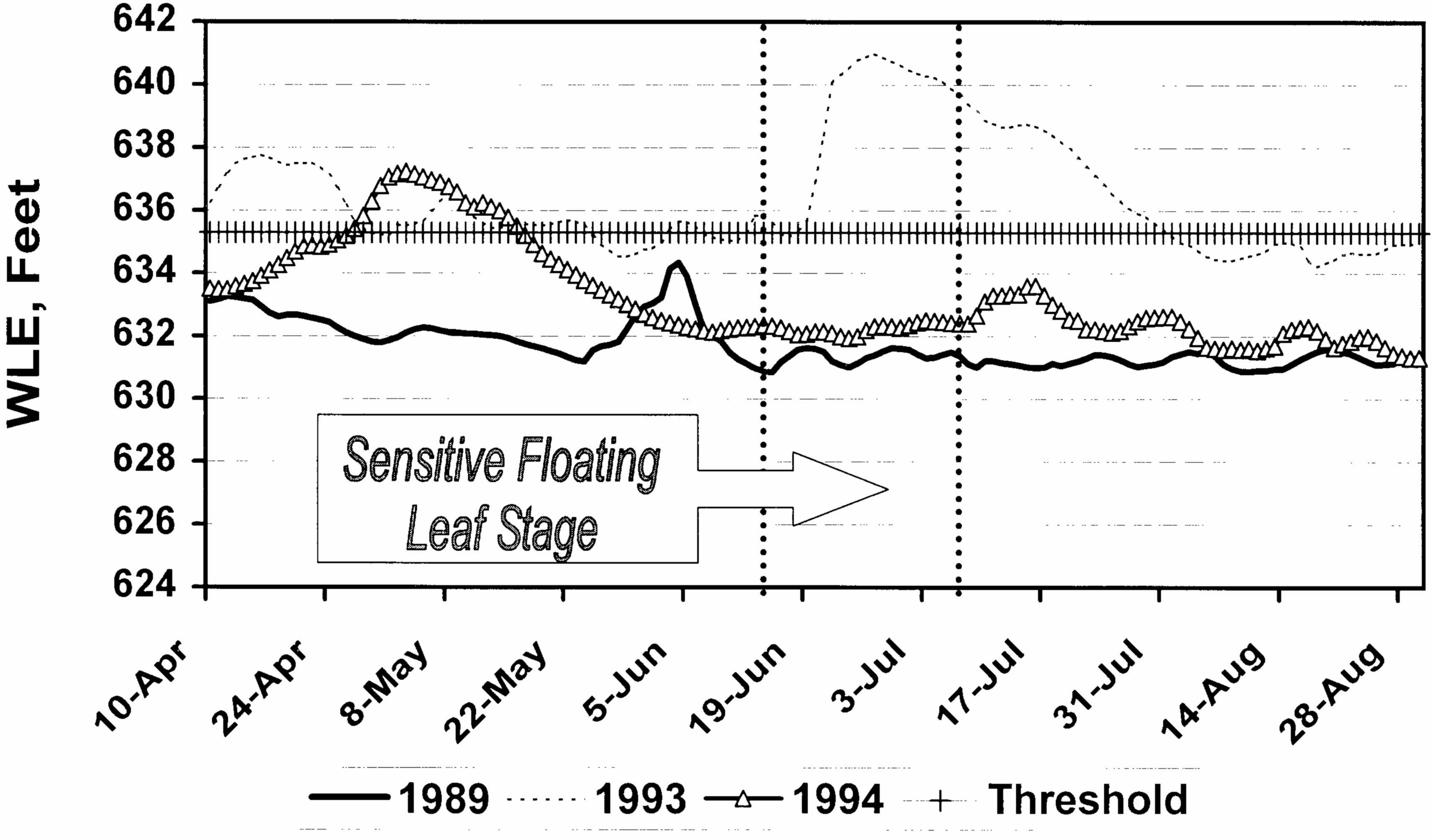
Water Velocity and Depth

During the flood of 1993, water velocities at the fixed backwater sites reached 0.3 ft./sec (0.1 m/sec) in Target Lake and exceeded 1.0 ft./sec (0.3 m/sec) in Lawrence Lake (Long Term Resource Monitoring Program Water Quality Database, U. S. Geological Survey Upper Midwest Environmental Sciences Center web site, http://www.umesc.usgs.gov/data_library/water_quality/water_quality_page.html). Long Term Resource Monitoring Program staff observed many uprooted aquatic plants. If they were not uprooted, floating-leafed species such as water lilies and some submergents responded to increased water depths with adaptive measures such as stem elongation (Dukerschein, personal communication with H. A. Langrehr, Wisconsin Department of Natural Resources, Onalaska). Adaptations such as these could have potentially decreased energy stores available for the following year's growth (1994), which showed relatively low poolwide percentages of both rooted floating-leafed plants and the combination of rooted floating-leafed plants/submergents. (See Figure 2.)

Water Level Elevation and Acres of Pure Wild Rice Delineated

Of the years where pure stands of wild rice delineated totaled less than 20 acres (8.1 ha), water level elevations in 1989 and 1993 were the most atypical. (See Figure 3.) 1989 was a drought year with abnormally low water level elevations in the spring and an abnormal peak in mid-June. The peak in June was below the defined flood threshold of 635.4 ft water level elevation for this study, but it rose and fell rapidly enough that it could have disturbed the floating leaf stage of growth occurring

Figure 3: La Crosse Gage, 8:00 AM Daily WLE, Relative to Flood Threshold at 635.3 Feet



at that time. The 100-year flood in the summer of 1993 was unusual both in timing (occurring during peak plant biomass in summer) and in duration (lasting more than 6 weeks). (See Figure 3.) It was widely observed up and down the Mississippi River that the unusual summer flooding in 1993 uprooted or disturbed the growth of many species of aquatic plants. The shallow root system of wild rice makes it particularly vulnerable to such disturbances during its growing season. Although water levels in 1991 and 1992 fluctuated more than is ideal, fluctuations did not prevent the growth of wild rice. A fringe of wild rice less than one acre was observed in the field in Blue Lake both years.

In 1994, water level elevations rose above the defined flood threshold in late April, gradually came down to typical summer levels by June 6, and remained low and stable through the floating-leaf stage of growth. (See Figure 3.) The large disturbance the year before and the stable water levels during the 1994 growing season created favorable growth conditions for an opportunistic annual plant such as wild rice that can survive in dormant seed banks for five years or more. The defined flood threshold of 635.3 ft (193.7 m) was exceeded in all years from 1994 through 1998. A water level elevation spike of more than 2 ft (0.6 m) in late May 1997 just prior to the floating-leaf stage may or may not have uprooted submergent wild rice plants. Field observations indicated that a 5-foot (1.5 m) spike combined with strong winds in late June of 1998 uprooted wild rice plants in portions of Blue Lake (Dukerschein, personal communication with R. Nissen, Wisconsin Department of Natural Resources, La Crosse).

The increase in wild rice cover in 1994 was large enough that spatial auto-correlation due to seed-drop or other factors could account for the wild rice cover in subsequent years. Whatever the mechanism, graphs of the flood duration and magnitude index (feet per year exceeding 635.3 ft Water Level Elevation at the La Crosse gage) combined with acres of pure wild rice delineated appear to show a relationship between acres of wild rice delineated and flood duration and magnitude. (See Figure 4.) It is interesting to note that wild rice was delineated following pre-floating-leaf-stage disturbances at index levels of as little as 20 ft (6.1 m) per year in years following the 1993 flood, but it was not delineated at these index levels or even at twice those levels in the years we monitored prior to the flood of 1993. This evidence suggests that the flood of 1993 might have played a role in resetting the successional clock for wild rice in these backwaters. Reports by long-time residents and biologists and actual delineations on photos provide evidence that wild rice was present in Lawrence Lake in 1975 and in the mid-1980s. It has been present in various areas of Blue Lake off and on since the 1940s. The reoccurrence of wild rice in 1994 supports literature reports that it can survive in buried seed banks for five years or more.

Apparent response to the flood of 1993 in each of the three backwaters studied varied, but all showed some response in 1994. Lawrence Lake showed a relatively moderate response of 82 acres (33.2 ha) of pure wild rice delineated in 1994, and it showed the best response of the three backwaters in 1997 with 105 acres (42.5 ha) of pure wild rice delineated. (See Figure 4.) Acres of pure wild rice delineated in Blue Lake exceeded 350 acres (141.6 ha) in 1994. (See Figure 5.) Only 17 acres (6.9 ha) of pure wild rice were delineated in Target Lake in 1994, with no pure stands of wild rice delineated prior to or following that, although sparse stands of wild rice were observed growing in Target Lake in 1992 (Dukerschein, personal communication with H. A. Langrehr, Wisconsin Department of Natural Resources, Onalaska). If all backwaters are combined on one graph, what looks like a strong relationship between the pre-floating-leaf stage flood index and acres of pure wild rice is apparent. (See Figure 6.) This must be interpreted with caution because there can be many variables.

In conclusion, mechanisms related to flooding could likely be addressed by the following hypotheses, variations of which have been stated previously in the scientific literature.

- A pre-season disturbance (summer flood in

Figure 4: Lawrence Lake, Pool 8

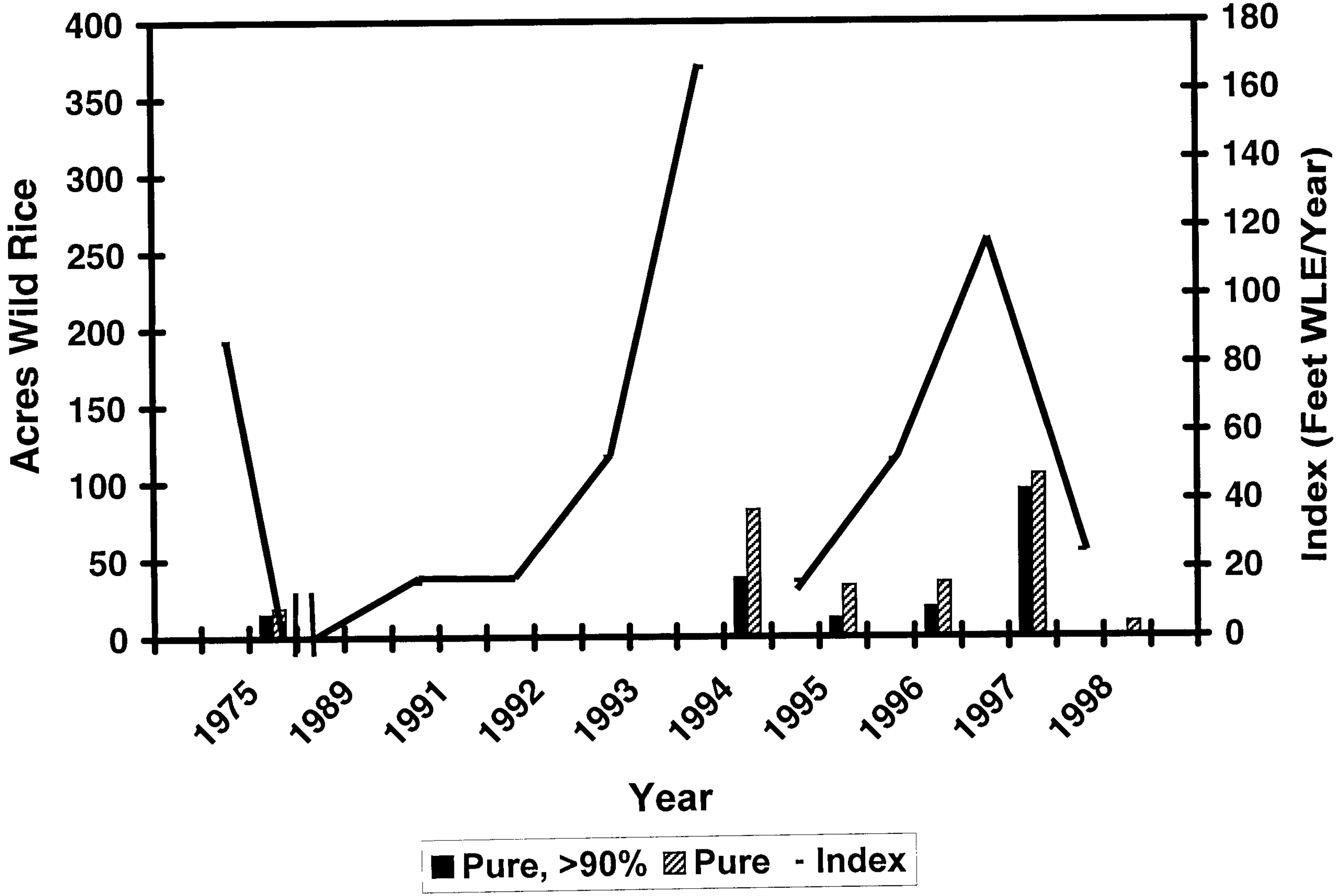


Figure 5: Blue Lake, Pool 8

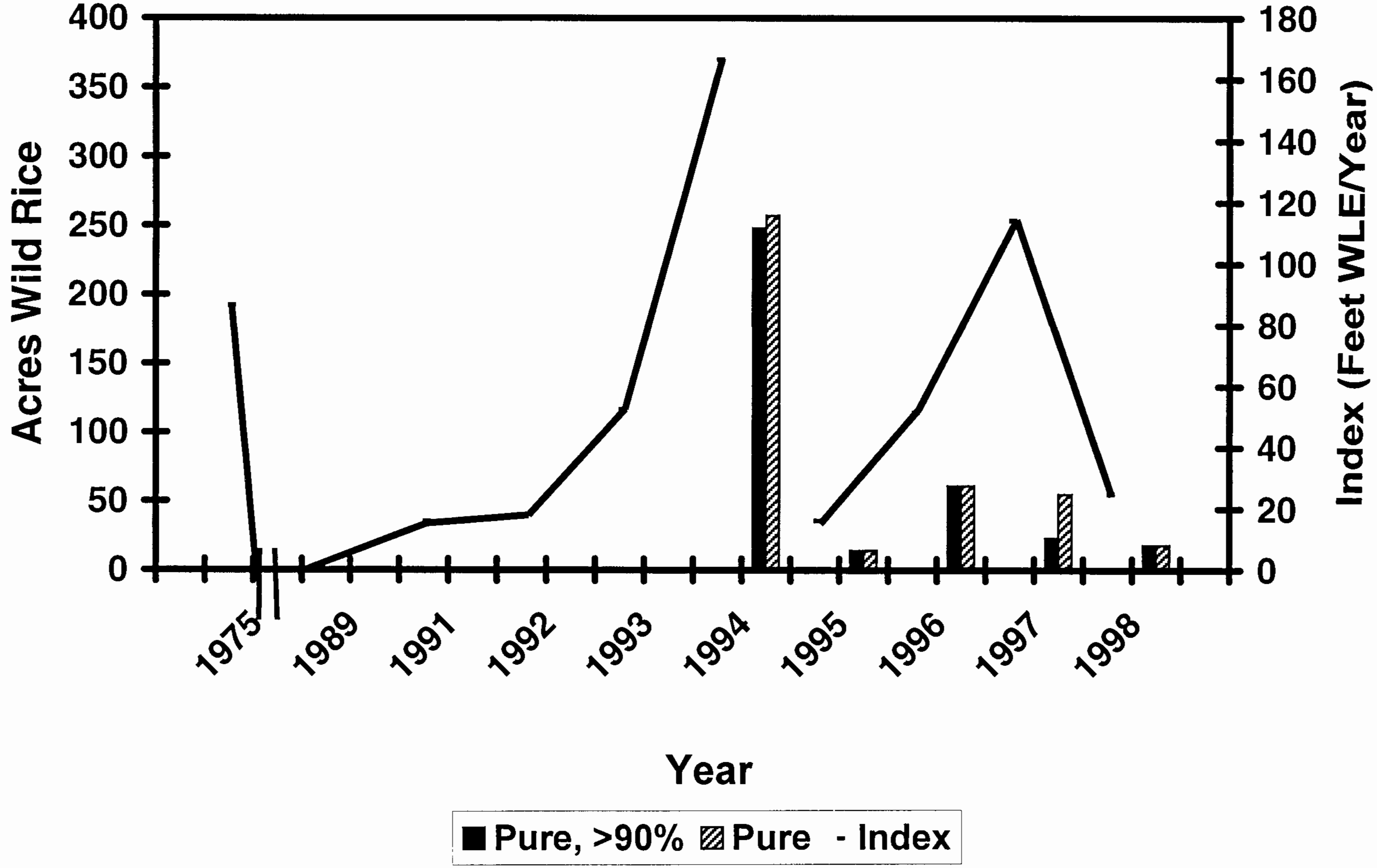
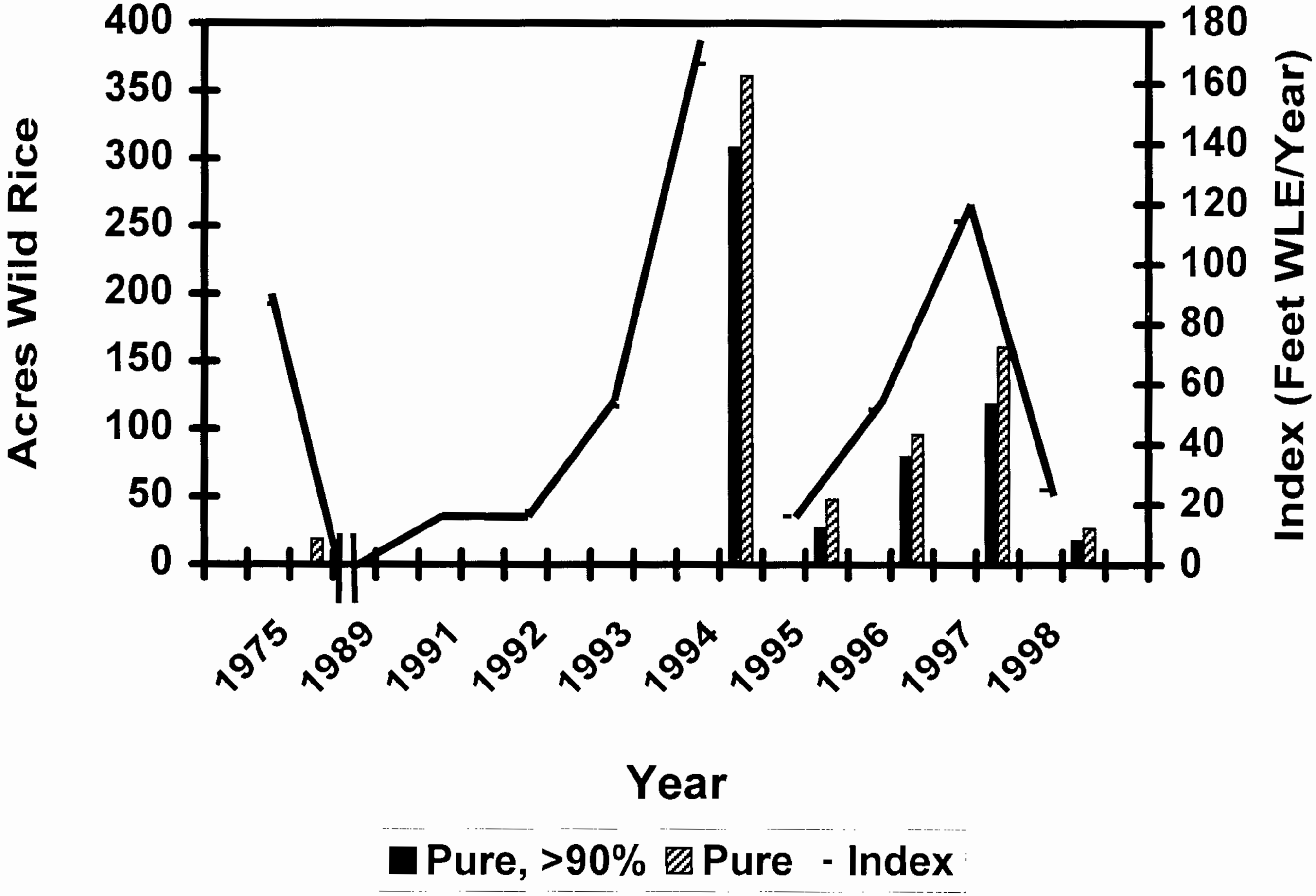


Figure 6: All Backwaters, Pool 8



this case) can remove competing plants (especially perennials) and leave open spots where viable, persistent seed banks of plants like wild rice can germinate and flourish due to lack of competition for nutrients and light from other plants (Keddy and Reznicek 1986).

- Wild rice growing in river systems needs properly timed inflow and deposition of nutrient-rich sediments to do well (Meeker 1996). The flood of 1993, although a relatively "clear-water" flood, because of its magnitude and duration, could have deposited increased amounts of nutrient-rich sediments in backwaters, especially since it occurred near peak biomass for aquatic plants and established plant beds in some areas could have slowed velocities enough for sediment deposition to occur.
- Tillage from the flood could have cleansed sediments or created a more favorable sediment alkalinity or oxidation-reduction environment where known critical nutrients such as P, Na, Ca, Zn, soluble K, Cu, Mn, SO_4, Cl, and Fe were more available.
- Tillage from the flood could have re-exposed or scarified (stimulated) a previously buried seed bank.

Additional, site-specific factors that could interact with these flood-related hypotheses include geomorphological characteristics of backwaters such as shoreline length, distance from the main channel, and type of connection to the main channel; sediment composition; water temperature; water clarity; carp spawning and predation by carp; motorboat activity (Dore 1969); wind fetch; and exposure of seeds in sediments to freezing (Vertucci et al. 1995).

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REFERENCES

Arzigian CM, Boszhardt RF, Theler JL, Rodell RL, Scott MJ. Human adaptation in the Upper Mississippi Valley: A study of the Pammel Creek Oneota Site (47Lc61), La Crosse, Wisconsin. 1989. Wis Arch 70 (1-2).

Dore WG. 1969. Wild-rice. Canadian Department of Agriculture and Plant Research Institute Publication 1393. 84 pp.

Jenks AE. 1977. The wild rice gatherers of the Upper Lakes: A study in American primitive economics. Reprints in Anthro 9. Lincoln, Neb: J & L Reprint Co.

Kahl R. 1993. Aquatic macrophyte ecology in the Upper Winnebago Lakes, Wisconsin. Technical Bulletin 182. Wisconsin Department of Natural Resources. 60 pp.

Keddy PA, AA Reznicek. 1986. Great Lakes vegetation dynamics: The role of fluctuating water levels and buried seeds. Journ of Great Lakes Res 12(1):25-36.

Meeker JE. 1996. Wild-rice and sedimentation processes in a Lake Superior coastal wetland. Wetlands 16(2):219-31.

Moyle JB. 1944. Wild rice in Minnesota. Journ of Wildlife Management 8:177-84.

Moyle JB, Hotchkiss N. 1945. The aquatic and marsh vegetation of Minnesota and its value to waterfowl. Technical Bulletin 3. Minnesota Department of Conservation.

Richter BD, Baumgartner JV, Powell J, Braun DP. 1996. A method for assessing hydrologic alteration within ecosystems. Conserv Biol 10:1163-74.

Rogers SJ, Owens TW. 1995. Long term resource monitoring procedures: Vegetation monitoring. LTRMP 95-P002-3. National Biological Service, Environmental Management Technical Center.

Rogosin A. 1957. The Minnesota Academy of Science Proceedings. XXV-XXVI:95-7.

Soballe D. 1993. Chapter 5: Water quality monitoring. In: Procedures manual of the long term resource monitoring program for the Upper Mississippi River system. EMTC 93-P011 (draft). U. S. Fish and Wildlife Service. Environmental Management Technical Center.

U. S. Fish and Wildlife Service. 1994. Federal Register 59(219):58,991.

Vertucci CW, Crane J, Porter RA, Oelke EA. 1995. Survival of *Zizania* embryos in relation to water content, temperature and maturity status. Seed Science Research 5:31-40.

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POSTER/ORAL PRESENTATION

PRODUCTIVITY OF NATIVE WILD RICE BEDS

Dave Wise

ABSTRACT

For centuries, wild rice (*Zizania aquatica*) has been a staple in the American Indian culture. Primarily, it was the major food source. It was also critical in maintaining the wildlife on which the people depended for food, clothing, and utensils. Lastly, it was one of the largest sources of revenue derived directly from the natural resources.

However, natural wild rice stands (beds) found in the forested areas of Minnesota have historically been neglected and funds to study and manage this valuable resource have been insufficient. As a result, it is felt that much of the state's original wild rice productivity has been significantly reduced due to overall loss of acreage; declining habitat quality, including water contamination and irregular lake levels (during critical stages of plant growth); and reduction of rice plant populations by encroachment of exotic species.

Therefore, Fond du Lac Tribal and Community College proposes a detailed analysis of the wild rice bed conditions on 14 selected lakes and one river flowage. The information obtained may be compared with previous data, if available, or act as a baseline and documentation for future considerations. The knowledge is also urgently needed by Tribes of the 1854 Ceded Territory of northeastern Minnesota that have accepted management responsibility for wild rice on these lakes.

INTRODUCTION

The Productivity of Native Wild Rice Beds Project being conducted through Fond du Lac Tribal and Community College (FDLTCC) is a cooperative effort to monitor the quality, density, and productivity of selected 1854 Ceded Territory lakes that are distinguished in wild rice (*Zinzania palustris*) production in order to help to develop best management practices of resources. The information gathered is fundamental in helping to understand the ecological relationships of the lakes and watersheds, to plan the management of the wild rice lakes, and to educate our communities on the importance of wild rice as a key component of our environment.

STUDY PARAMETERS

The study area consists of 14 lakes and one river flowage within the 1854 Ceded Territory of northeastern Minnesota. The relationship between wild rice and other associated plants and the water quality and sediment characteristics and nutrients of the lake ecosystems are being investigated. Data collection began approximately two years ago and will continue indefinitely. The following parameters are being studied.

Wetland Ecosystem: Plant Communities: species diversity, wild rice and other plant densities and productivity, and plant locations in relationship to water depth, water clarity, sediment type, and lotic zone.

Aquatic Ecosystem: Water Quality: pH, secchi depth, ammonia, nitrate and nitrite, TKN, orthophosphate, total phosphorus, suspended solids, sulfate, and water temperature.

Sediment Characteristics and Nutrients: particle size and type, TKN, ammonia, nitrate and nitrite, total phosphorus, total solids, and TVS.

Lake Morphology: water depth, bottom type, vegetation type, and location of springs.

Hydrological Data Collection and Modeling: Hydrology Data Collection: lake water elevation, stream flows, and precipitation.

Wild Rice Ecosystem Monitoring: Global Positioning System and Geographical Information System: location and mapping of wild rice and plant community locations and densities.

CONCLUSION

Through the project, FDLTCC has had the opportunity to help develop an educational approach to wild rice resource management. The FDLTCC is pursuing funding opportunities to extend the project to allow for continued data collection and expand the project to include wild rice lakes on the Fond du Lac reservation. In order to acquire effective regulatory tools to protect and enhance our complex water systems, the unique historical and traditional aspects of wild rice, the driving forces that impact it, and the current condition of wild rice resources on lakes of the 1854 Ceded Territory must be understood. This is being accomplished in part through a variety of educational workshops and media carried out through the project that are intended to help create a consensual effort to improve native rice bed quality, condition, and acreage; to promote from the Native American perspective an understanding of the history, ecology, genetics, and native culture surrounding wild rice; and to develop a common agreement to foster and enhance our existing wild rice resources.

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